Non-Destructive Testing of Meat Using Interdigital and Meander Type Sensors

Sharifah Sakeenah Syed Abdullah[1], Sara Bilal[2] and Khairul Azami Sidek[1]

[1]*Department of Electrical and Computer Engineering, Faculty of Engineering, International Islamic University Malaysia, 53100 Jalan Gombak, Kuala Lumpur, Malaysia.*

[2]*Department of Science in Engineering, Faculty of Engineering, International Islamic University Malaysia, 53100 Jalan Gombak, Kuala Lumpur, Malaysia.*

azami@iium.edu.my

***Abstract*—Adulterations in labeling of meats, especially for halal product consumers can be considered as a major problem. This study is designed to qualitatively differentiate between beef and pork meats using a non-destructive method. A total of 250 grams of raw beef and pork meat samples have been collected from different parts of the meats. Unique characteristics such as resonance frequency, S-parameter and impedance of the meats were detected and classified by two types of sensors. The sensors which are planar interdigital and planar meander sensors have been fabricated using IPC and FR4 substrate respectively. Testing of the beef and pork meat was done separately. The performance of the system was reliant on the accuracy obtained from the sensors based on the mentioned characteristics. When using the interdigital sensor, it has been found that the average impedance of the pork meat parts is always higher than the average impedance of the beef meat parts of 2.71MΩ as compared to 1.68MΩ. This can be due to the fact that the beef meat contains more density of muscles compared with the pork meat. Meanwhile, when using the grounded meander sensor, the average S21 (dB) was up to -16.177dB for pork meat and -19.515dB for beef meat. The results have shown that the interdigital and meander sensors can be used to differentiate between beef and pork meat. In the future, these sensors may be developed into a portable device known as a non-destructive test to distinguish beef from pork meat.**

***Index Terms*—Adulteration in Meat; Impedance; Interdigital Sensor; Meander Sensor.**

I. INTRODUCTION

Non-destructive testing (NDT) is a technique used in science and industry in order to determine the properties of a material, component, system or quantitatively measure some characteristics of an object without causing any damage on it. The purpose of this research is to find out the possibility of using the sensors on a non-destructive testing of meat; specifically on beef and pork.

Meat is mainly composed of water, fat and protein and is usually eaten unprocessed or processed in a variety of ways. Meat consumption varies worldwide, depending on cultural or religious preferences, as well as economic conditions. Statistical data in the year 2003 shows that beef is the third most widely consumed meat in the world; accounting for about 25% of meat production worldwide, after pork and poultry at 38% and 30% respectively [1]. From that, we have noticed that pork is the most commonly consumed meat worldwide. This is due to the life process of the pigs where a young female pig is reproductively mature around the age of eight months. Sows typically give birth to eight or nine piglets with each litter, with some litters having as many as 12 piglets.

II. LITERATURE REVIEW

There are three methods to determine the meat types which are DNA extraction, image processing and planar electromagnetic sensors. These approaches are briefly described next.

A. DNA Extraction

Large quantities of DNA from very small samples are able to be produce in a short time by using the Polymerase Chain Reaction (PCR). Recent studies outlined by Ibrahim Abdullah suggest that using ASL buffer for Iyses to isolate DNA from meat samples was reliable and subsequently. It is obvious that DNA primers could be used to amplify the species-specific 152-bp porcine leptin fragment [2]. Similarly, a theory shows that the third TaqMan PCR system, developed on the basis of the detection of my statin gene permits a reliable exclusion of false-negative results by detecting meat from variety poultry in the material to be used [3].

B. Image Processing

A research based on describing a method to determine a meats quality using the concept of "marbling score" and texture analyses had been carried out by [4]. The study used a grey level occurrence matrix as a texture pattern and makes a standard texture feature vector for each grade using it. The marbling score in the rib-eye standard was determined by calculating the percentage of fats in the 7 rib eye region. The disadvantage using "marbling score" or texture pattern recognition is when the grading is performed in a refrigerator at a low temperature; this will make it difficult for grader to make a decision. Another experiment on image processing for characterization of the fat/meat ratio and fat distribution of pork and beef samples has been conducted by [5]. The researchers used statistical analysis of RGB to classify the segment of the image in identifying between the fat, meat and the background.

C. Planar Electromagnetic Sensors

Research conducted by [6] evaluates the nondestructive testing of meat using planar electromagnetic sensor. This type of sensor is a quite sensitive sensor to detect the fat in the meat samples. They have tested four main varieties of pork meat which are fat, mixed, muscle and skin. They were analyzing the sensor result to see the effect of different amount of fat content to the impedance of the sensor (See Figure 1).

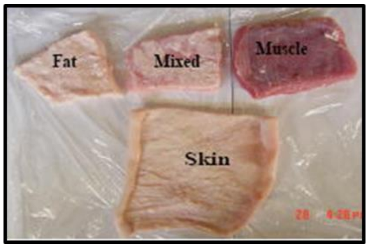


Figure 1: Pork sample for test [6]

III. METHODOLOGY

Figure 2 describes the experiments conducted in this research.

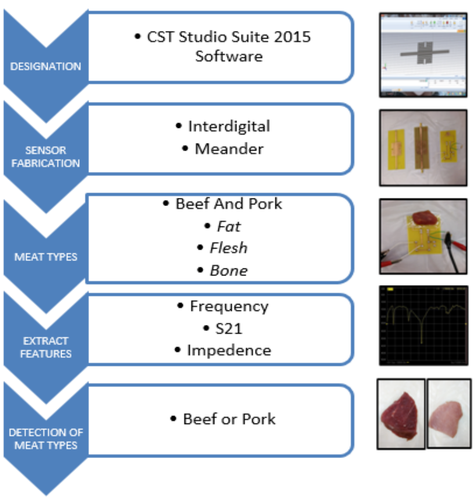


Figure 2: The process of identifying the meat type

A. Sensor Designation

Both interdigital and meander type sensors were first designed using the Computer Simulation Technology (CST) Studio Suite 2015 Software. The software was the culmination of research and development into the most accurate and efficient computational solutions for electromagnetic designs. Once the designation is done, it was export to the Agilent Advanced Design System 2011.05 to have an accurate measurement before it was printed out on a transparency paper for fabrication process (see Figures 3 and 4).

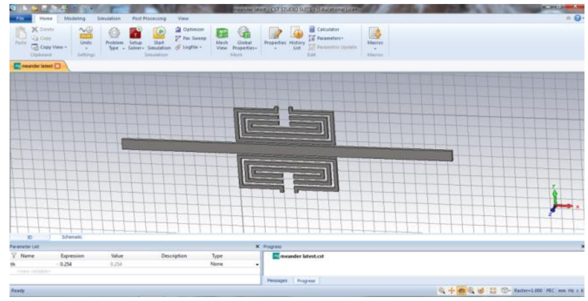


Figure 3: Meander type sensor using CST Studio Suite 2015

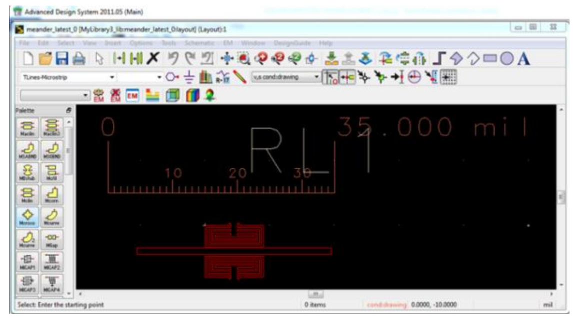


Figure 4: Meander type sensor using Agilent Design System

B. Sensor Fabrication

Two types of sensors have been fabricated for this study which are the planar interdigital and meander sensors. These sensors are described in the next sub-sections.

1) Planar Interdigital Sensor

Basically the operation of planar interdigital sensor, follows the rule of two parallel plate capacitors, at which the electrodes open up to give a one sided access to the material under test (MUT).

One type of interdigital sensor has been designed and fabricated. The layout of the sensor was proposed by [7] which results best for the sensor sensitivity. The sensor was designed with effective area of 5.00mm by 5.00mm and having pitch of 0.25mm .The positive and negative electrodes have the same length and width of 4.75mm and 0.25mm respectively. Figure 5 shows the fabricated interdigital sensor.

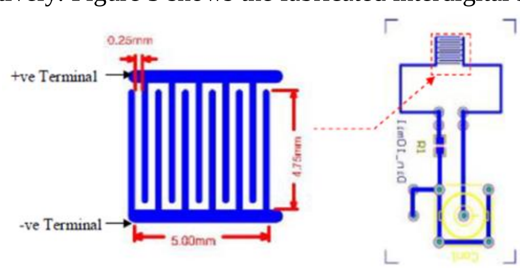


Figure 5: Fabricated interdigital sensor

2) Planar Meander Sensor

The Aligned-Gap Multiple Split Ring Resonator (SRR) which was known as the meander type sensor was designed to sense a liquid material by [8] from Department of Computer and Communication Systems Engineering, UPM. The basic idea of implementing the multiple SRR was to manage the distributed capacitance between the strips without increasing the size of the resonator, leading to lower resonance frequency.

The structure proposed to design the sensor was in a way to increase high field region at the split and decrease the operating frequency due to increment of capacitance value. The dielectric changes is detected as there is an interaction of the extended splits designed to be material under test (MUT).Generally SRR can be approximated by LC resonant circuit with resonance frequency as in Equation 1. The resonant frequency was determined from capacitance and inductance of the unit cell which based on the dimension and structural design of the metamaterial structure.

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

where *f*: frequency, *L*: inductance, *C*: capacitance.

To obtain high sensitivity, a sharp resonance dip in frequency response and high concentration of electric field was needed to ensure the detection of MUT. Hence, in this project a rectangular SRR was designed to enhance the sensitivity performance of the sensor. Figures 6 and 7 show the layout of the sensor.

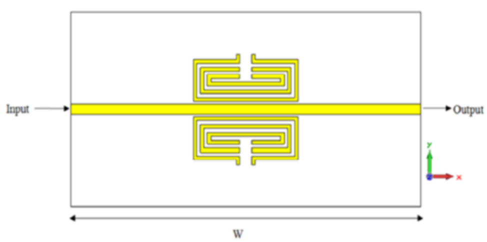


Figure 6: Sensor layout

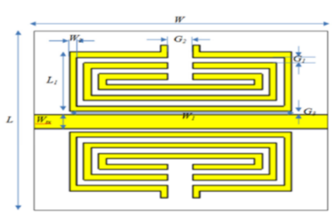


Figure 7: Sensor's schematic design

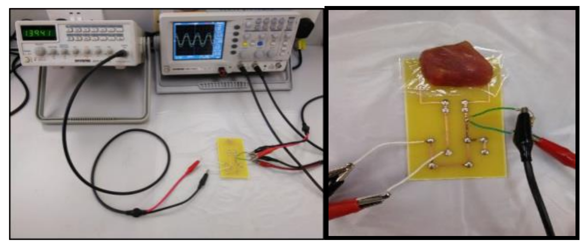
IV. Experimental Setup

After the two planar sensors have been fabricated, it is then tested using the two types of meat.

A. *Testing the Beef and Pork Using the Planar Interdigital Sensor*

Planar interdigital sensor has the same operations principle of two parallel plate capacitors. Figure 9 shows the representation of the equivalent circuit diagram for the interdigital sensor. An excitation dc voltage was applied to the sensor (Vin) creating an electric field by the sensor in the system of MUT. The voltage (Vs) across the series of the resistance (Rs) to measure the current (Is) flowing to the sensor. For this project, the value of Rs selected was 120kΩ as it produced a good sensing voltage (Vs) and a better phase different which was close to 90◦,so that the real part of the circuit can be neglected.

The experimental set up of the fabricated planar interdigital sensor is shown in Figures 9(a) & (b) respectively. A frequency of 1.4 MHz with 16 Vpp (Voltage peak-to-peak) was applied to the sensor using Gwinstek Function Generator. Gwinstek Digital Storage Oscilloscope was used to observe the waveform and the excitation as well as the sensing signal. The measurement of the excitation and sensing parameters value from the sensor were calculated (See Figure 8).



(a) (b)

Figure 8 (a) & 8(b): Experimental setup for interdigital sensor analysis

The sensor impedance can be calculated by

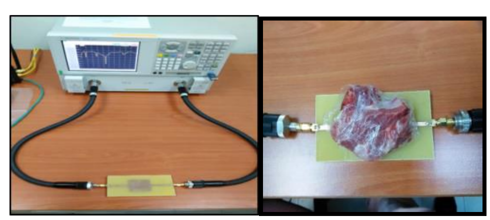
$$Z = \frac{Vin}{Is} = \frac{Vin}{Vs/R} \quad (2)$$

$$Z = \frac{Vin}{Vs} * Rs \quad (3)$$

where *Z:* Impedance,
Vin: Voltage across the sensor,
Vs: Voltage across the series of resistor, Rs, and
Is: The current flowing through the sensor.

B. *Testing the Pork and Beef Planar Using the Meander Sensor*

Two types of meander sensor have been fabricated. One was grounded and another one was not grounded. SMA connectors were mounted onboth end of the micro strip transmission line and directly connected to Agilent Technology N5230A Network Analyzer (VNA) for S-parameter measurement. Figures 9(a) & 9(b) show the fabricated meander sensor and the experimental set up respectively.



(a) (b)

Figure 9: Experimental setup for meander sensor analysis

Basically, S-parameter described the magnitude and phase relationship between the incident and reflected wave and was numbered according to the wave origins and the propagation. A common notation used is m and n for the general S-parameter (Smn), where m was the receiver port an n was the source port. Hence, in this project, we were focusing on the S21 that stand for transmission coefficient for a wave sourced at port 2 and received at port 1.The S-parameter carried both a magnitude and phase component as a function of frequency.

Equations 4 and 5 show the 2-port S-parameter equations.

$$b_1 = S_{11}a_1 + S_{12}a_2 \tag{4}$$

$$b_2 = S_{21}a_1 + S_{22}a_2 \tag{5}$$

Formal equation definition of S-parameters is as in Equation 6.

$$\left\{ \begin{array}{ll} S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} & S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0} \\ S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} & S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0} \end{array} \right\} \tag{6}$$

The electric field within the split gap was observed in order to obtain the purpose structure as a sensing element. An intense and localized electric field was very sensitive to any dielectric sample in the development of the SRR structure generally. Figure 10 shows a strong electric field between the gaps and resonance frequency.

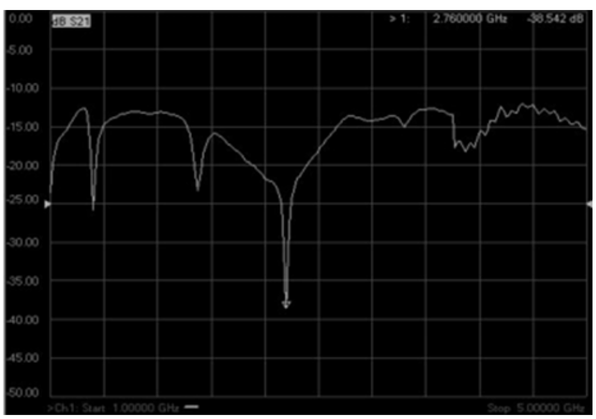


Figure 10: S21 in dB at 2.76 GHz for meander type sensor

In this work, we were considering more on the changes of impedance for both sensors. Hence, Equation 7 can be used to measure the impedance value of this meander type sensor.

$$z = \pm\sqrt{\frac{(1+s11)^2 - s21^2}{(1-s11)^2 - s21^2}} \tag{7}$$

where z*:* Impedance,
s*11:* Reflection and
s*21:* Transmission.

V. Results And Circuit Analysis

A. Planar Digital Sensor

The interdigital sensor was connected with a series surface mount resistor to measure the current through the sensor. An excitation voltage of 16 *Vpp* with 1.4 MHz was applied to the circuit. The resistor selected was 120kΩ as it shows the best waveform. Two experiments were conducted using the interdigital sensor. The first experiment was to measure the impedance of fat, flesh and bone for both beef and pork meats. The second experiment was to compare the impedance of fat between beef and pork.

The impedance characteristic of the fabricated interdigital sensor was observed through the relationship between the voltage inputs in the excitation signal, output voltage in the sensing parameters using the 120kΩ resistor

From Table 1, it can be seen that the impedance value for each parts of the pork was high compared to the beef. It can also be seen that there was much difference of impedance value between the beef and pork fat. This was due to the nature of the beef meat comparable to the port meat. In addition, another experiment was conducted specifically to measure the impedance of fat between beef and pork.

Table 1
Relationship between excitation voltage, sensing voltage, current and impedance of the planar interdigital sensor

	Excitation Parameters		Sensing Parameters			
PART OF MEAT	Frequency (GHz)	Vin (V)	Vs (mV)	Is (mA)	Vin/Vs (V)	Impedence (MΩ)
BEEF (fat)	1.4	8.4	480	4	17.5	2.1
PORK (fat)	1.4	8.4	460	3.83	18.26	2.19
BEEF (flesh)	1.4	8.4	620	5.17	13.55	1.63
PORK (flesh)	1.4	8.4	540	4.5	15.56	1.87
BEEF (bone)	1.4	8.4	600	5	14	1.68
PORK (bone)	1.4	8.4	300	2.5	28	3.36

B. Planar Meander Sensor

In resonant method, the resonance frequency was changed when the meat under test (MUT) was interacted with the electric field distribution. Different waveforms were obtained using different parts of the beef and pork meat. The three parts of beef and pork meat investigated were fat, flesh and bone. Two experiments were conducted for this sensor.

This experiment was conducted to measure the S21 and impedance for different parts of beef and pork using the ungrounded meander sensor. Two samples were used for each part and the average measurement was taken. Table 2 shows the results obtained using different parts of beef and pork.

From Table 2, it was obvious that the resonance frequency for pork was much higher compared to beef with 2.76 GHz and 2.74GHz, respectively. The trend of the measured value between different parts of the beef and pork meat can be concluded that the pork having a higher value of S21 (dB) and impedance (Ω) compared to beef.

Table 2
Measured S21 and impedance of different parts of beef and pork

M E A T	F=Fat M=Meat B=Bone	Freq. (GHz)	S21 (dB)	Average S21 (dB)	Impedance (Ω)	Average Impedance (Ω)
	Electric Parameters					
	F1	2.74	-33.73	-36.79	51.96	51.14
B	F2	2.74	-39.85		50.32	
E	M1	2.74	-34.07	-33.06	51.33	51.28
E	M2	2.74	-32.04		51.23	
F	B1	2.74	-30.98	-32.67	47.89	49.41
	B2	2.74	-34.36		50.93	
	F1	2.76	-37.90	-34.50	51.93	51.50
P	F2	2.76	-31.10		51.06	
O	M1	2.76	-28.13	-29.24	53.71	52.86
R	M2	2.76	-30.35		52.01	
K	B1	2.76	-32.85	-32.32	52.50	52.30
	B2	2.76	-31.80		52.09	

VI. Discussion

By observing the results obtained in the experiments conducted using both the planar interdigital sensor and the meander sensor, it can be concluded that the planar interdigital sensor shows best result for lower frequency while the planar meander sensor shows best result in term of higher frequency. The experiments conducted have shown that both types of sensors can be used to differentiate the beef and pork meat based on the frequency, S-Parameter and the impedance using different parts of the meat such as fat, flesh and bone. The impedance of each part of the pork meat is much higher compared to the beef meat when using the planar interdigital sensor. This was due to the fact that the beef meat has much muscle compared to the pork meat. This implies that the beef meat impedance was very low. This was naturally true because the beef meat structure was very connected compared to the pork meat which was very tender [9].

In addition, the line graph in Figure 11 shows a comparison between a grounded and ungrounded result for planar meander sensor. It can be concluded that the planar meander sensor which has been grounded shows better results. As the ground part of the sensor act as a shielding in order to avoid more reflection to be occurred.

VII. Benchmarking The Results

This research was conducted to investigate a non-destructive method to differentiate between beef and pork meat. During the sensors fabrication stage, we have found that using a meander type sensor without grounding was not the best choice for such experiments. Therefore, the experiments have been repeated for the meander sensor with and without grounding. In [8], the meander sensor has been used for testing various solvent such as water, methanol and ethanol. Meanwhile in our experiments, meander sensor has been used to identify beef from pork meat. In addition, testing the beef and pork meat using interdigital sensor was a successful step to find the difference between beef and pork compared to the work done by [6] were their work mainly based on pork cuts. The current experiments was conducted based on the fact that the beef meat contains more muscles that can put it in the category of a good conductor (from physics perspective) compared to the pork meat. Tables summarize this comparison with the existing work and the cost of fabricated sensors.

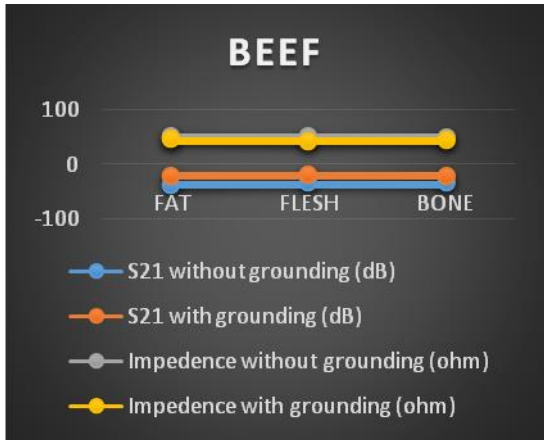


Figure 11: Comparison between ungrounded and grounded planar meander sensor on the fat, flesh and bone of the beef.

VIII. Conclusion

This work has described the interaction of planar electromagnetic sensors with samples of different parts of beef and pork meat cuts. A planar interdigital sensor has been fabricated. The sensor shows the differences of impedance for each part of beef and pork cuts. For beef meat, the average impedance obtained was 1.68MΩ. Meanwhile, the pork meat has given higher impedance of up to 2.71MΩ. The sensor results in a good possibility of using this sensor in differentiating the beef and pork in a non-destructive way. As for the planar meander sensor, two sensors have been fabricated and the grounded sensor shows the best result in term of frequency, S21(dB) and impedance. This can be observed from the results obtained from the grounded sensor where for beef meat the S21(dB) is always low (-19.515 dB) and S21(dB) is high for pork up to (-16.177dB).

References

[1] Retrieved May 1, 2015, from http://en.wikipedia.org/wiki/Beef

[2] I. A. Alaraidh, "Improved DNA extraction method for porcine contaminants, detection in imported meat to the Saudi market". *Saudi Journal of Biological Sciences*, vol. 15, no. 22, pp. 225-229, 2008.

[3] I. Laube, A. Spiegelberg, A. Butschke, J. Zagon, M. Schauzu, L. Kroh, &H. Broll. "Methods for the detection of beef and pork in foods using real-time polymerase chain reaction". *International Journal of Food Science &Technology* vol. 38, no. 2, pp. 111-118, 2003.

[4] K. Shiranita, K. Hayashi, &A. Otsubo. "Determination of meat quality using texture features". *IEICE TRANSACTIONS on Information and Systems*, vol. 83, no. 9, pp. 1790-1796, 2000.

[5] J. Felfoldi, L. Baranyai, F. Firtha, L. Friedrich, &C. Balla,2013. "Image processing based method for characterization of the fat/meat ratio and fat distribution of pork and beef samples". *Progress in Agricultural Engineering Sciences*, vol. 9, no. 1, pp. 27-53.

[6] S. C. Mukhopadhyay, C. P. Gooneratne and G. S. Gupta, "Non-invasive Testing of Quality of Pork Meat: Novel Planar Electromagnetic Sensors Based Approach". In *Proc. Instrumentation and Measurement Technology Conference, IEEE,* 2006, pp. 1947-1952.

[7] A. Rahman and M. S. Bin, Novel sensor design for detection of dangerous contaminated marine bio toxins: a thesis submitted in fulfilment of the requirements for the degree of Master of Engineering in

Information and Telecommunication Engineering, School of Engineering and Advanced Technology, Massey University, Palmerston North, New Zealand, 2009.

[8] I. M. Rusni, A. Ismail, A. R. Alhawary, M. N. Hamidon and N. A. Yusof, "Aligned-gap multiple split ring resonator for dielectric sensing application". In *Proc. 4th International Conference on Engineering Technology and Technopreneuship,* 2014, pp. 143-147.

[9] G. Heinz and P. Hautzinger, Novel planar electromagnetic sensors: Modeling and performance evaluation. *Sensors*, vol. 5, no. 12, pp. 546-579, 2009, cers. *RAP Publication (FAO)*.

Table 3
Comparison between the Developed System and the Existing Systems

	Reference	PCB Board Used	Methodology Software Used	Material Tested	Advantages	Disadvantages
Meander type sensor	[8]	Rogers RT5880	CST Software	Water, methanol and ethanol	High frequency of substrate	Unsmooth surface and expensive
	Developed Method	FR4	CST Software	Beef and pork	Cheap and perfect conductor of substrate	Lossy dielectric
Interdigital type sensor	[6]	FR4	Comsol Software	Pork	Large effective area	High cost
	Developed Method	IPC	CST Software	Beef and pork	Easy to handle	Small effective area