Development of Microstrip Patch Antenna Sensing System for Salinity and Sugar Detection in Water

E.M. Cheng*[,1], M. Fareq[2], Shahriman A. B.[1], Mohd Afendi R.[1], Y. S. Lee[3], S. F. Khor[2], W.H. Tan[1], Nashrul Fazli M. N.[1], A. Z. Abdullah[2] and M. A. Jusoh[2]
[1]School of Mechatronic Engineering, Universiti Malaysia Perlis, UniMAP, 02600 Arau, Perlis, Malaysia
emcheng@unimap.edu.my*
shahriman@unimap.edu.my
afendirojan@unimap.edu.my
whtan@unimap.edu.my
nashrul@unimap.edu.my
[2]School of Electrical System Engineering, Universiti Malaysia Perlis, UniMAP, 02600 Arau, Perlis, Malaysia
mfareq@unimap.edu.my
sfkhor@unimap.edu.my
zaidiabdullah@unimap.edu.my
asrijusoh@unimap.edu.my
[3]School of Computer and Communication Engineering, Universiti Malaysia Perlis, UniMAP, 02600 Arau, Perlis, Malaysia
dragon_lys888@yahoo.com
*Corresponding author：E.M. Cheng

***Abstract*— Microstrip patch antenna is a flat shape, light weight and low cost antenna that used to receive and transmit electromagnetic wave. This paper describes the design and development of a microstrip patch antenna for salinity and sugar detection. The microstrip antenna was designed and fabricated using Computer Simulation Technology (CST) Microwave Studio and Taconic TLY-5 substrate, respectively. This sensor is operate in the Industrial, Scientific and Medical (ISM) radio band, i.e. 2.45GHz. Dimension and shape of the patch antenna as well as location of feed point is analyzed. There are three types of microstrip patch antennas are developed in this work, i.e. rectangular, circular and square patch microstrip antennas. These microstrip patch antennas were used to measure the salt and sugar content in water. In addition, reflection coefficient and Q-factor were discussed too in this paper. Different amount of salt or sugar that present in water will exhibit different dielectric properties, and in turn change its reflection coefficient and Q-factor.**

***Index Term*— microstrip patch antenna; sugar; salinity; reflection coefficient; dielectric properties; Q-factor.**

I. Introduction

Nowadays, population of having diseases such as kidney failure, diabetes, stroke, etc. is increasing due to excessive intake of food product that highly contains salt and sugar. Various techniques have been proposed to determine the salt and sugar content in the food product. Some of these techniques include a study based on conventional drying method [1] and microwave measurement technique, e.g. open-ended coaxial probe was used for dielectric measurement on concentration of starch in a salt starch solution [2]. However, these techniques are time-consuming, complicated and expensive. Recently, microstrip antennas have been widely used in many applications such as communications, medical [3] and agriculture, for instance, Yahaya *et al.* [4] developed a microstrip patch antenna for determination of moisture content of hevea rubber latex. In this work, rectangular, circular and square microstrip patch antennas were designed to determine the salt and sugar content in water at 2.45 GHz (ISM bands).

Microstrip antennas are also crucial in variety of applications as transmitters and or receivers in our modern wireless society. So far no literatures reported 2.45 GHz application of microstrip antenna in salt and sugar sensing. The 2.45 GHz microstrip antennas can be considered as a sensor in food or agricultural products, firstly introduced in this paper for substance determination in water. However, many methods [5-12] exist for the determination of moisture content and soluble solids content in agriculture products. However, these methods are complex and very tedious to be conducted and cause severe error during the measurement.

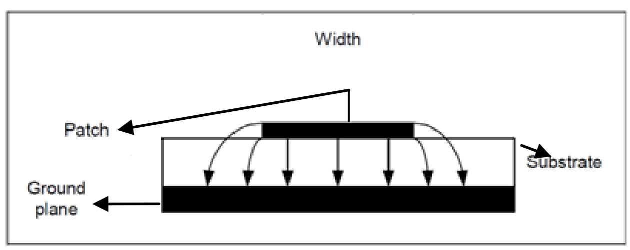

Fig. 1. Electromagnetic wave fringe from the top patch into the substrate [6].

II. PRINCIPLE OF MICROSTRIP ANTENNA

The radiation of electromagnetic wave from microstrip patch antenna is due to the fringing field from the top patch into the substrate, as shown in Fig. 1, it will reflected from the ground plane and radiate out from the microstrip patch antenna to the air. Therefore, the performances of the microstrip patch sensor will be affected by permittivity (ε_r) of the substrate and the dimension of patch. In this work, the thickness and the permittivity of the subscribe substrate is 1.575mm and 2.2, respectively as given in data sheet.

Feeding technique is used to supply the signal sources to the microstrip patch sensor. Coaxial probe feed feeding technique is used in this project. The feed mechanism of this technique is direct contact with the patch [13] and hence, it is more efficient compared to others technique in minimizing the spurious radiation. As a result, antenna can perform in broader bandwidth. In addition, the location of coaxial probe feed on the patch will influence the input impedance of the microstrip patch antenna too.

There are various factors that affect the performances of the microstrip patch antenna, e.g. size of patch, feed point location and shapes of patch. The resonance frequency of the microstrip patches antenna change with dimension of microstrip patch. Thus, the optimum dimension of patch and location of feeding point location must be first determined, in order to maintain its optimum performance using CST Microwave Studio.

Gadani *et al.* [14] reported that the dielectric constant and loss factor decrease, when the salt or sugar content in the sample increases (moisture content decrease). As discussed by Mudgett [15], the addition of salt to water leads to the variation on dielectric properties, because the addition of dissolved ions binds with water molecules. It leads to reduction in polarization of the water and a decrement in the dielectric constant and loss factor.

According to Brinley *et al.* [16], the molecule of sugar form hydrogen bonding with free water molecules. It degrades the ability of water molecules in polarization. Therefore, dielectric constant, ε' and dielectric loss factor, ε'' decreases when sugar content in water increases. Decrement in dielectric properties of material under test will cause decrement in effective dielectric constant, $\varepsilon_{eff,}$, and in turn load impedance, Z_L increases. As a results, reflection coefficient , $|\Gamma|$ decreases.

On the other hand, the Q-factor is also a measured parameter to analyze the returned results from the antenna based on the sugar and salt content in solution. Per literature published by Joshi (1997) [17], resonance frequency of the microstrip patch sensor is sensitive to the moisture level. In other word, Q-factor is function of both dielectric factor, ε', and dielectric loss, ε'', of the measured sample.

III. Materials and methods

A. *Samples*

Salt (NaCl) is a crystalline compound which can be dissolved in water. The salt is presented in ionic state, when the salts dissolve in water. Meanwhile, sugar or sucrose ($C_{12}H_{22}O_{11}$) is a crystalline shape compound that appears in white, odourless, and with a sweet flavoured. Both substances are crystalline compounds which can dissolve in water.

B. *Antenna Design*

CST Microwave Studio is used to design microstrip antenna and their performance is simulated for comparison. Various shapes of patch are designed, e.g. rectangular, square, and circular shape, for the sake of comparison of performances as antenna sensing system.

First, import database of Taconic TLY-5 substrate into CST Microwave Studio. Dimension of microstrip patch on substrate must be determined by referring to simulated reflection coefficient via CST Microwave Studio. The dimension of microstrip patch can be determined after the desired reflection coefficient is acquired. On the other hand, the best feed point location can be found also by referring to the reflection coefficient that returns in CST Microwave Studio. At last, Taconic TLY-5 substrate is fabricated to be the microstrip patch antenna as shown in Fig. 1.

(a) (b)

Fig. 1. Fabricated microstrip square patch antenna in (a) bottom and (b) top view .

C. *Experimental work*

In this work, experimental setup for reflection measurement was conducted using fabricated microstrip patch antennas in conjunction with P-series network analyzer (Fig. 2). The measured reflection coefficient was compared with Agilent 85070E High-Temperature dielectric probe. The reflection measurement is illustrated in Fig. 3.

Fig. 2. P-Series Network Analyzer (PNA)

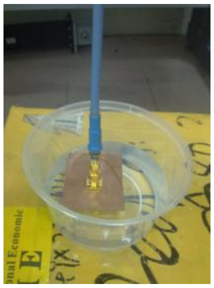

Fig. 3. Reflection measurement on water

IV. RESULTS AND DISCUSSION

A. Simulation

By using CST Microwave Studio, different shape of patch antenna is simulated, as shown in Fig. 4.

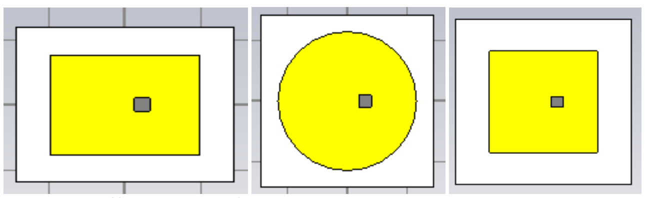

Fig. 4. Different shape of microstrip patch is simulated by using CST Microwave Studio.

As mentioned in section III, the microstrip patch antennas are designed by using CST Microwave Studio. The desired reflection coefficient presented by each antenna must be ≤0.3162 (-10dB) [18] and operate at 2.45GHz [19]. There are few factors that need to be considered, i.e. dimension of patch, shape of patch, and location of feed point.

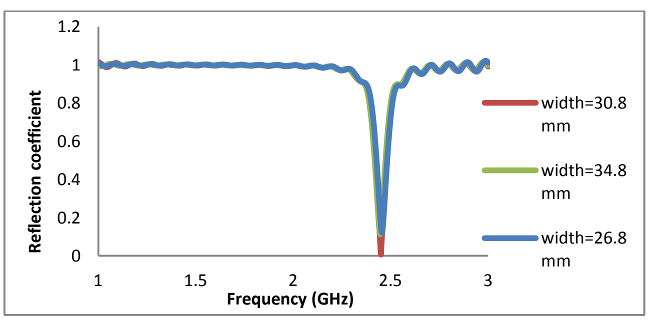

Fig. 5. Variation of simulated reflection coefficient with different width of microstrip patch antenna.

Fig. 5 illustrate simulated result attributed to the effect different width of rectangular microstrip patch on reflection coefficient. Fig. 5 shows that the increment of patch width to 34.8mm will cause reflection coefficient decrease to 0.1127. Meanwhile, when the patch width decreases to 26.8mm, reflection coefficient increases to 0.1230. It implies that increment of patch width cause increment of power radiate through patch and thus decrease resonance resistance and increase radiation efficiency [20]. When the width of patch width is found to be 30.8mm, the reflection coefficient exhibit the lowest value, i.e. 0.0062. Therefore, width of patch with 30.8mm is the optimum width.

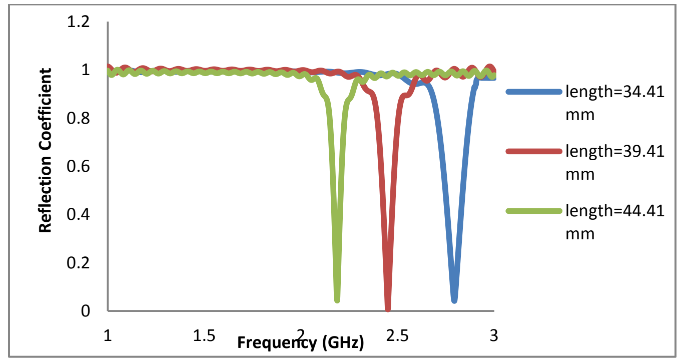

Fig. 6. Variation of simulated reflection coefficient with different length of rectangular microstrip patch.

Fig. 6 is similar to Fig. 5, as which it illustrates the effect of length of patch on the reflection coefficient over frequency. Fig. 6 indicates that when the length of patch increases, the resonance frequency will shift to left (lower frequency). The optimum length of patch is found, i.e. 39.41mm, because it shows the minimum peak of reflection coefficient at 2.45GHz (resonant frequency). Hence, it can be known that length of microstrip patch is function of resonance frequency [21].

An optimum location of feed point must be determined to obtain a minimum impedance mismatch [22]. In other word, improper location of feed point will cause the unwanted reflection occurred. When the desired location of feed point i.e. 4.5mm from center of patch is met, the reflection coefficient is the lowest (0.0062) among other location, as shown in Fig. 7.

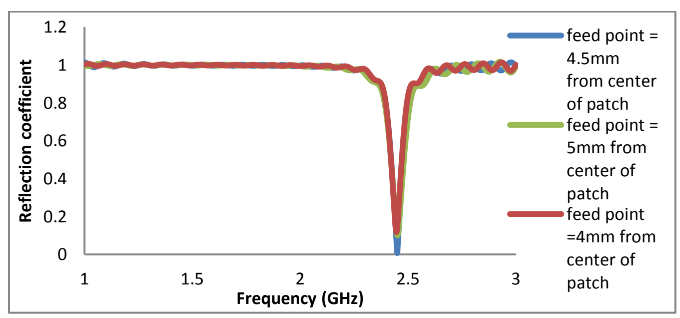

Fig. 7. Variation of simulated reflection coefficient with different location of feed point on rectangular microstrip patch antenna.

There are 3 shapes of microstrip patch are discussed. The shape of patch affects the distribution of current on the conducting patch and radiation characteristics of the antenna. Fig. 8 shows that the rectangular microstrip patch antenna dispaly the lowest value of reflection coefficient, i.e., follow by square microstrip patch sensor with reflection coefficient of 0.0403 and the circular microstrip patch sensor show the highest value of reflection coefficient, i.e. 0.0737. Therefore, the rectangular microstrip patch antenna is decided as the best shape in this work.

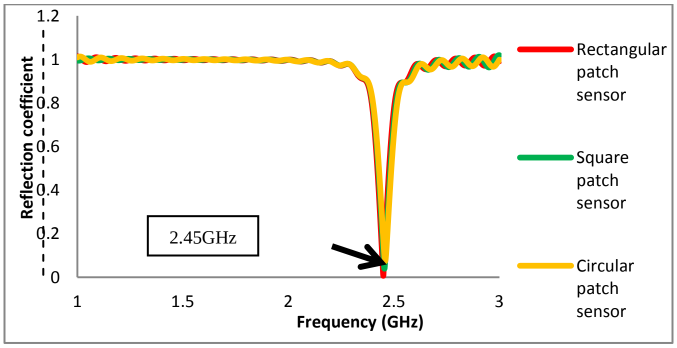

Fig. 8. Comparison of simulated reflection coefficient in different shape of patch in microstrip patch antenna

Optimum characteristics of microstrip patch antenna are as summarized in Table I, II and III.

Table I.
Dimension of rectangular microstrip patch antennas

Parameters	Values
Width of substrate	57.6mm
Length of substrate	47.6mm
Width of patch	30.8mm
Length of patch	39.41mm
Feed point location	4.5mm from centre point of x-axis
Thickness of the antenna	1.645mm
Dielectric constant of the substrate (ε_r)	2.2

Table II.
Dimension of circular microstrip patch antennas

Parameters	Values
Width / length of substrate	57mm
Radius of the patch	23mm
Feed point location	5.5mm from centre point of x-axis
Thickness of the antenna	1.645mm
Dielectric constant of the substrate (ε_r)	2.2

Table III.
Dimension of square microstrip patch antennas

Parameters	Values
Width / length of substrate	64.8mm
Width / length of patch	39.2mm
Feed point location	5mm from centre point of x-axis
Thickness of the antenna	1.645mm
Dielectric constant of the substrate (ε_r)	2.2

B. *Measurement*

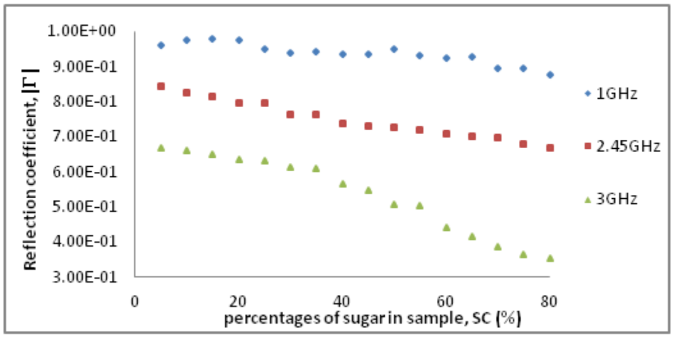

Fig. 9. Variation of reflection coefficient with percentage of sugar content in solution for 1 GHz, 2.45 GHz and 3 GHz.

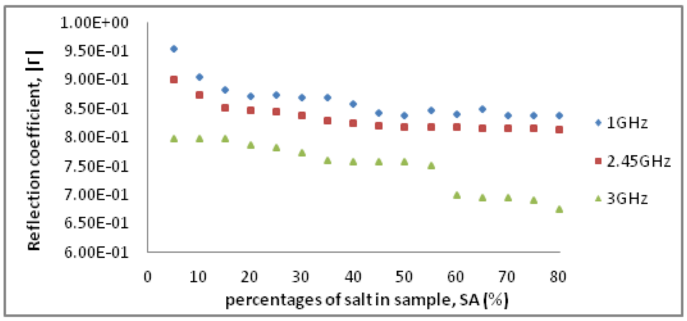

Fig. 10. Variation of reflection coefficient with percentage of salt content in solution for 1 GHz, 2.45 GHz and 3 GHz.

From Fig. 9 and 10, it can be observed that the reflection coefficient at 1GHz, 2.45GHz and 3GHz decrease when the percentage of sugar or salt in solution increases. It is due to the decrement of free water molecule [23] when the percentage of salt and sugar content increase. As mentioned previously, low mobility of water molecules as well as ionic substance might be the main cause. Hence, the degree of mismatch impedance is reduced and causes reduction of reflection coefficient when the percentage of salt and sugar content increase. It is due to the decrement of dielectric constant and loss factor of solution, since free water molecules are reduced. Decrement of complex permittivity, ε^*, of the sample lead to reduction of effective dielectric constant, ε_{eff} of sample. In turn, reduction of ε_{eff} decrease load impedance, Z_L . At last, it causes the decrement reflection coefficient, |Γ|, as shown in Fig. 9 and 10.

Q-factor as expressed in Eq. (1) in microwave measurement is defined as the ratio of the energy stored in the sample to the energy dissipated in sample, at a particular frequency (the resonance frequency), f_r, where the stored energy is constant with time.

$$Q = \frac{\Delta f}{f_r} = \frac{f_s - f_r}{f_r} \qquad (1)$$

where, f_r = resonant frequency,

f_s = shifted frequency.

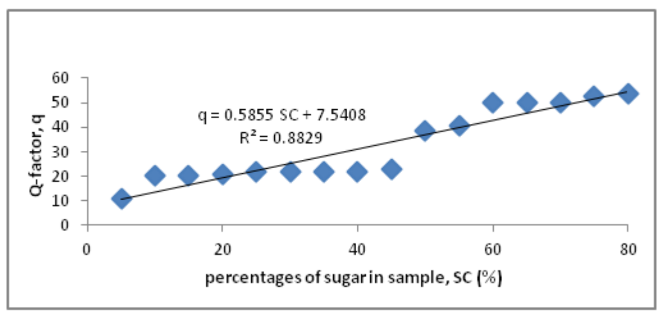

Fig. 11. Variation of measured Q-factor using rectangular microstrip patch antenna with percentages of sugar in solution

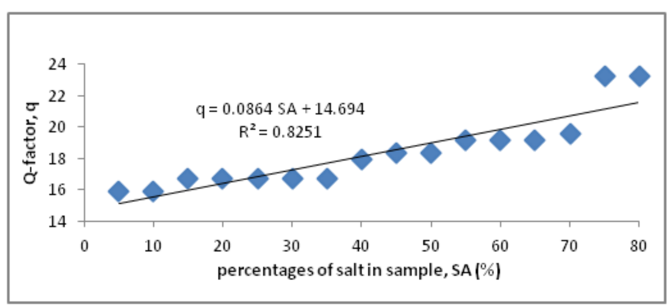

Fig. 12. Variation of measured Q-factor using rectangular microstrip patch antenna with percentages of salt in solution

From Fig. 11 and 12, it can be observed that Q-factor increases with percentages of sugar and salt in solution. All

IJENS

the antennas were designed, so that the resonance frequency in free space which indicate the minimum peak by reflection coefficient at ISM band (2.45 GHz). However, when the antenna is exposed in some material which is dissimilar with dielectric properties as in free space, the minimum peak of reflection coefficient will shift to another value of resonance frequency. The degree of discrepancy from the resonance frequency at free space is determined by the dielectric properties of sample. The discrepancy can be quantified by Eq. (1). It can be noticed that the presence of salt and sugar content in solution change the dielectric properties of solution, and thus increase the discrepancy of resonance frequency linearly when compare with case in free space. The linearity can be gauged through the coefficient of determination, R^2 for linear fitted equation which describe the relationship of Q-factor with percentage of salt and sugar content in solution.

III. Conclusion

A low cost microstrip patch antenna is developed as antenna sensing system for salt and sugar content in solution. The microstrip patch antennas are designed by using CST Microwave Studio and fabricated by using Taconic TLY-5 substrate. The antennas are simulated, in order to obtain the optimum dimension for this work. After simulation and comparison, rectangular microstrip patch sensor with width and length of patch, given as 57.6mm and 47.6mm, respectively. This dimension indicates the lowest reflection coefficient, i.e. 0.0063, among other microstrip patch antennas.

In reflection measurement of sugar and salt content in solution, reflection coefficient decrease as percentage increase. It is attributed to the reduction of dielectric constant and loss factor water molecule, as which water molecules are constraint and confine the mobility of molecules in solution.

In addition, Q-factors increases linearly as the salt and sugar content in solution increase. It can be justified by the considerable high of coefficient of determination, R^2 as shown in Fig. 11 and 12. The designed rectangular patch antenna as specified in Table I show highest sensitivity for sugar measurement.

This work introduce a low cost setup for authority, food industry runner or consumer to identify the level of sugar and salt in food or beverage, since the level of sugar and salt content is mandatory and under regulation.

Acknowledgment

The authors gratefully acknowledge Universiti Malaysia Perlis (UniMAP) for supporting this work financially. In the meantime, author would like to deliver the deepest gratitude to Research Cluster of Embedded Computing, UniMAP for the research equipments.

References

[1] Karen L, and Gartley. "Recommended Methods for Measuring Soluble Salts in Soils," Cooperative Bulletin, 493, pp.123-243, 1954

[2] C. Bircan and S. A. Barringer. "Salt–Starch Interactions as Evidenced by Viscosity and Dielectric Property Measurements," Journal of Food Sciences, 63, pp. 983-985, 1988

[3] Ali Daliri, Amir Galehdar, Sabu John, Wayne S. T. Rowe and Kamran Ghorbani. "Circular Microstrip Patch Antenna Strain Sensor for Wireless Structural Health Monitoring**."** Proceedings of the World Congress on Engineering 2010 Vol II, WCE 2010, June 30 - July 2, 2010, London, U.K.

[4] N. Z. Yahaya and Z. Abbas. "Determination of Moisture Content of Hevea Rubber Latex Using a Microstrip Patch Antenna, PIERS Proceedings, pp.1290-1293, 2012.

[5] Chung JH, Verma LR, "Measurement of rice moisture during drying using resistance-type sensors," American Society of Agricultural Engineers, 1991, 7(5): 630-635.

[6] Thomasson JA, "Cotton moisture measurement with a black-and-white video camera," American Society of Agricultural Engineers, 1995, 11(3): 371-375.

[7] Jayanthy T, and Sankaranarayanan P., Measurement of dry rubber content in latex using microwave technique," Measurement Science Review 5: 3, 2005.

[8] Abbas Z, Mokhtar R, Khalid K, Hashim M and Abdul-Aziz S, "RDWG technique of determination of moisture content in oil palm fruits." Eur Phys J-Appl Phys. 40: 207-210, 2007.

[9] Ghretli M, Khalid K, Grozescu I, Sahri M and Abbas Z, "Dual frequency microwave moisture sensor based on circular microstrip antenna," IEEE Sensors Journal 7 (12): 1749-1756, 2007.

[10] Sundaram J, Chari VK, Christopher LB, and William RW, "Application of NIR reflectance spectroscopy on determination of moisture content of peanuts: A non-destructive analysis method," Paper presented at ASABE Annual International Meeting. Reno, Nevada, June 21-June 24, 2009.

[11] Lee K, Abbas Z, Yeow Y, Nur Sharizan M, Meng C, "In situ measurements of complex permittivity and moisture content in oil palm fruits," Eur Phys J-Appl Phys. 49: 31201-31206, 2010.

[12] Seifi MR, and Alimardani R, "Comparison of moisture dependent physical and mechanical properties of two varieties of corn (Sc 704 and Dc 370)," Aust J Agric Eng 1(5): 170-178, 2010.

[13] Zebu, "Electromagnetic Radiation," http://zebu.uoregon.edu/~imamura/122/lecture-2/em.html, 4 May 2013.

[14] D H Gadani, and V A Rana, "Effect of Salinity on Dielectrc Properties of Water," Sciences Direct, V50, 2012, pp405-410.

[15] Candace Deffendol, "Microstrip patch for Dielectric Property Measurement, Springer, 1999, pp 320-340.

[16] R. Zajicek, and T. Smejkal, "Medical Diagnostics Using Reflection Method and Waveguide Probes - Feasibility Study," Progress In Electromagnetics Research Symposium, Cambridge, USA, pp.759-763, 2008.

[17] Shondganga, "Chapter VI: Discussion of the results of the studies of Soybean, Sunflower and Groundnut using overlay on microstrip components and waveguide techniques," unpublished.

[18] Signal Processing Group Inc., "VSWR, Reflection coefficient, Return loss, S11/S22, Cambridge, MA, 2009.

[19] Company Yageo, "2.45 GHz ISM-band antenna for Bluetooth and WLAN IEEE 802.11b: Surface-mount ceramic multilayer antennas," Phycomp, company Yageo, 2002.

[20] Kai Fong Lee and Wei Chen. *Advances in Microstrip and Printed Antennas*, John Wiley, 1997.

[21] Vijay Sharma, and Nitin Agrawal, "Amelioration of Rectangular Microstrip Patch Sensor Characteristics by Integrating it with Left-Handed Inspired Metamaterial in L-Band," Research Report, Madhav Institute of Technology and Science, India, 2012.

[20] D. Orban and G.J.K. Moernaut, "The Basics of Patch Antennas," Orban Microwave Products,1, pp.2-7, 2011.

[23] Xiaoming He, Alex Fowler and Mehmet Toner. "Water activity and mobility in solutions of glycerol and small molecular weight sugars: Implication for cryo- and lyopreservation" J. Appl. Phys. 100, 074702 (2006).