International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING

ISSN:2147-6799 www.ijisae.org Original Research Paper

Quality Evaluation of an Apple using Non- Invasive Microwave Technique

Dr. Sandeep V. Gaikwad [1], Dr. Ajay Yadaorao Borkar[2], Dr. Vijaya N. Aher [3], Dr. Rahul S. Pol [4], Dr. Daulappa G. Bhalke[5], Vishal G. Padwal[6]

Submitted: 19/08/2023 **Revised**: 09/10/2023 **Accepted**: 20/10/2023

Abstract*:* Fruit nutrition is the necessary part of human diet; hence determination of its quality has importance. The analysis of fruit quality is also a critical task in the commercial market. The non-invasive method is the most referred technique for quality evaluation. In this paper, the microwave technique is proposed and discussed. Both transmitter and receiver antennas are designed for a 2.45 GHz ISM band. In this paper, a microwave system is proposed to determine the different conditions of an apple, so that the rejection of the internally rotten apple is possible.

Keywords: *Dielectric constant, quality of fruit, rectangular patch antenna, non-invasive microwave technique.*

1. Introduction

Quality is the important aspect of fruit to the commercial market. The visual inspection and personal experience of people to decide fruit quality and image processing is the current trend used in food processing industry. An exterior part of the fruits is considered in both the methods to decide its quality. It often happens that exterior part of the fruit looks good but an interior part is rotten, this case remains exceptional for the image processing. The proposed microwave technique completely considers interior part of the fruit material [3]. Every fruit material has its own dielectric constant and it depends on temperature, moisture content and maturity level of fruit. Material properties like permittivity for desired frequency should be known for any analysis of microwaves on the fruit material. Permittivity is a complex quantity which is expressed as $\epsilon = \epsilon' - j\epsilon''$, where ϵ' is dielectric constant and ϵ'' is dielectric loss factor [1-2]. Thus, antenna system is the most important part of proposed method. Microwave radiated low power signals passes through the fruit and due to ϵ'' of the fruit material power loss occurs. The dielectric heating should not happen in fruit material, power to be applied can be calculated by [6-7][10]

$$dT/dt = 0.239 \times 10-6\ P/(c\rho) \qquad (1)$$

$$P = 55.63\ fE2\epsilon'' \times 10-12 \qquad (2)$$

Where c – specific heat of the dielectric, ρ – specific gravity, f – frequency, E – rms value of electric field intensity in V/m, P – power in W/m2. The received power depends on complex dielectric constant or permittivity. Later this received power is used to determine the degree of maturity.

The selection of microwave frequency should be such that it gives the promise to determine the quality of fruit. At the lower side of the microwave frequency range variation in dielectric constant appears and at the higher end of microwave frequency range, significant variation appears in dielectric loss factor [1][4]. Also, penetration of signal power is more hence lower microwave frequencies are more preferred. An ISM band of 2.45GHz frequency is used in the proposed method [2-4]. Signal power is kept low considering the nutritional values of fruit should not change.

2. Material and Methods

The quality testing of fruit has conducted by keeping a fruit in between transmitting antenna and receiving antenna inside the shielded enclosure. The radiated microwaves are passed through the fruit material using microstrip antenna and transferred microwave signal strength is monitored by the receiving antenna. Further the observed data is given for quality analysis. The basic block diagram of proposed system is shown in Fig. 1.

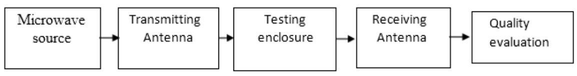


Fig. 1: Basic block diagram of proposed system

Dielectric properties of material

Material which comes under influence of electromagnetic waves has some electrical parameters considered as dielectric material. Every dielectric material has both electric and magnetic properties

[1,6]SCTR's Pune Institute of Computer Technology, Pune, India
[2]Cusrow Wadia Institute of Technology, Pune
[3,4]Vishwakarma Institute of Information Technology, Pune, India
[5]Dr. D. Y. Patil Institute of Technology Pimpri, Pune
** Corresponding Author Email: svgaikwad@pict.edu*

whereas these properties are decided upon how that material is incorporated with electric and magnetic waves respectively. The electric properties are permittivity, conductivity, capacitance and resistance while the magnetic properties are permeability, diamagnetism, and hysteresis.

In this paper an apple fruits are considered as a sample fruit. Every fruit has its own permittivity called as relative permittivity, whereas relative permittivity is complex quantity. As mentioned earlier, real part is dielectric constant and imaginary part is dielectric loss factor. The measured dielectric constant of an apple is used for further experimentation is shown in Table 1[1][9][11].

Table 1: Dielectric constant & loss factor of an apple (at 25^{0}C)

Time	Permittivity	Frequency (in MHz)		
		10	915	2450
Initial	ϵ'	70.0	52.2	50.4
	ϵ''	199.0	6.2	8.9
2 Weeks	ϵ'	65.5	52.3	50.4
	ϵ''	144.5	5.9	9.4
4 Weeks	ϵ'	73.5	53.4	51.6
	ϵ''	213.6	213.6	9.6
6 Weeks	ϵ'	68.0	54.0	52.2
	ϵ''	169.7	6.3	9.5

It has been recorded that the monotonic decrease in dielectric constant and dielectric loss factor as frequency increases in most of the fruits and vegetables [1-2]. The dielectric constant of an apple is increased as temperature increases from 50C to 650C and decreases as further temperature increases [2][4].

Design of rectangular microstrip patch antenna and testing enclosure:

For the proposed method low power, small size microstrip antenna has at 2.45GHz. The design equations to calculate the transmitter and receiver antennas parameters, are given below [6-7].

1. The width of rectangular microstrip patch antenna.

$$W = \frac{1}{2fr\sqrt{\varepsilon 0\mu 0}}\sqrt{\frac{2}{1+\epsilon r}} \qquad (3)$$

2. Effective dielectric constant of microstrip antenna

$$\epsilon reff = \frac{\epsilon r+1}{2} + \frac{\epsilon r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \qquad (4)$$

3. Extension of the length ΔL

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon reff+0.3)(\frac{W}{h}+0.264)}{(\epsilon reff-0.258)(\frac{W}{h}+0.8)} \qquad (5)$$

4. Length of patch is now determined by solving for L

$$L = \frac{1}{2fr\sqrt{\epsilon reff}\sqrt{\varepsilon 0\mu 0}} - 2\Delta L \qquad (6)$$

The dimensions of the transmitting and receiving antenna are decided based on the size of the fruit under test. The antenna parameters considered during the calculations are as given below:

fr = 2.45GHz, εr = 4.4 (FR4 epoxy), h = 1.6mm

The calculated values of the transmitting antenna is W=38.03mm & L=29.42mm. Later dimensions are optimised to W=38mm and L=27.8 for achieving better results. Substrate and ground plane dimensions are (6h+L) × (6h+W). Co-axial feed is given to rectangular patch antenna and the feed point is selected as (W/$\sqrt{\epsilon reff}$, L/2) [6-7].

The design of receiving antenna is quite tricky and important, so that the only through power has to be meased by the receiving antenna. According to the application, the size of receiving antenna needs to be miniatured such that, further use of multiple receiving antenna helps to plot image of an inner part of the fruit such as output of one antenna is one pixel. The stated design steps are used to calculate L= 28.7mm but to achieve miniaturization there is a need to add a rectangular slot of 18×7mm with the optimization using EM simulation tool (HFSS).Thus the length of patch is reduced up to 20.58mm retaining the same working frequency.

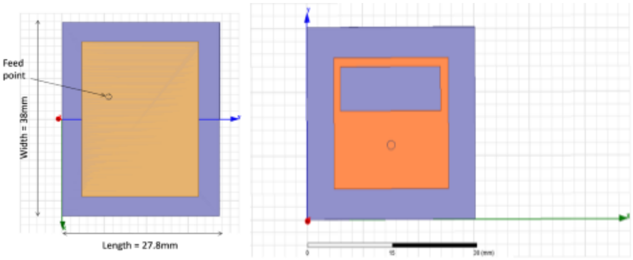


Fig. 2: Simulation design of transmitter rectangular & receiver square microstrip patch antenna.

The size of the testing enclosure is made up of aluminum sheet metal and its size is 30cm×30cm. To avoid the internal reflection flat foam absorber is used. The material of foam is soft polyurethane. This sample is prepared with soft polyurethane and graphite (30%). This mixture is poured in die and it is kept in oven and heated up to 65^{0}C. The soft polyurethane foam is prepared with density of ~ 65 kg/m3. The thickness of foam absorber is 18mm. As graphite is used in sample, it has property to absorb electric energy into it[12]. All the sides of case are packed with the flat foam absorber. The adjustable stand is used to keep fruit in the vicinity of far field of antenna.

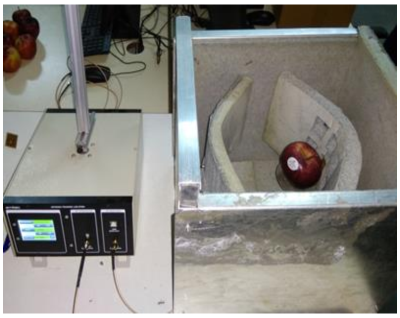
(a)

(b)

Fig. 3: Testing enclosure (a) and chemically treated soft polyurethane structure (b)

To understand the internal condition of an apple, a turn table is prepared and one receiving microstrip antenna has been used during the experimentation. Every sample is marked with 4 sections and rotated during testing. Diring the experimentation two variety of an apple has been taken as Red Delicious & Joly Red. The sample size decided here is three for different maturity condition after harvesting.

The source of microwave signal and the reciever system has connected to an antenna which are attached inside the enclosure for the purpose of quality testing of an apple. The setup is shown in the Fig. 4(a). The samples of two varieties of an apple is considered and is shown in Fig. 4(b).



(a)

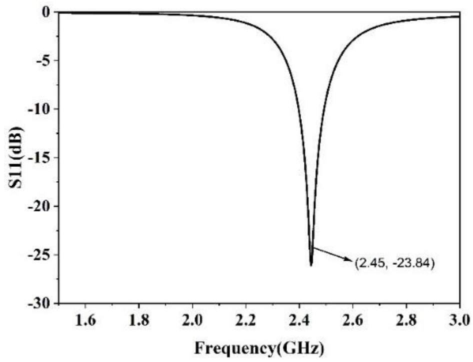
(b)

Fig. 4: (a) Microwave source and enclosure with antenna, (b) Samples of Apple used for experimentation

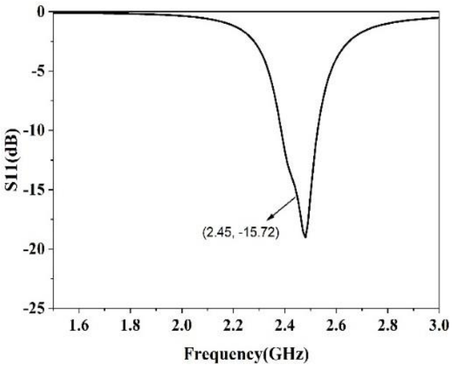
3. Results and Discussions

Simulation results for transmitting and receiving microstrip patch antenna:

As shown in Fig. 5; the S11 (Return Loss) of the simulated transmitting antenna is -23.84 dB and receiving antenna is -15.72 dB at 2.45GHz. The VSWR of the designed antenna is observed as 1.14 and 1.39 respectively.

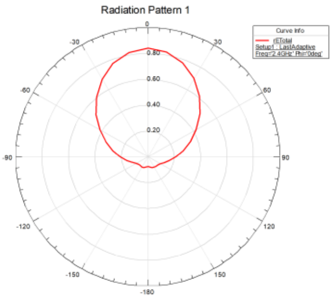


(a)

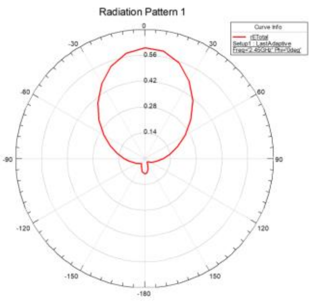


(b)

Fig. 5: Plot of S11 for designed Transmitter (a) and receiver (b) antenna.



(a)



(b)

Fig. 6: Polar plot of the radiation pattern of (a) transmitter and (b) receiver antenna.

As the designed antenna has to transmit microwaves power through the fruit, the expected radiation pattern of an antenna needs to be directive. Fig. 6. Showing the radiation pattern of designed antenna.

Testing of the developed antenna on VNA

The R&S- ZVL-VNA (9KHz to 13.6GHz) used to verify the results of developed antenna at 2.45 GHz. The S11 of the transmitter and receiver antenna is measured and testing set-up is shown in Fig. 7. The measured S11 of transmitter antenna is -24.98 dB and the receiving antenna is -12.65dB.

(a)

(b)

Fig. 7: Testing of an antenna on VNA (a) transmitter & (b) receiver

The Received power at different maturity levels of an apple after harvesting has been measured using above setup and the observation is shown in the Table 2.

Table 2: Dielectric constant & loss factor of an apple along with received power through an apple.

Duration of apple after harvesting	ε'	ε''	Received power through an apple (dB)
Premature	50.4	8.9	-23.02
2 weeks	50.4	9.4	-23.91
4 weeks	51.6	9.6	-24.14
6 weeks	52.2	9.5	-24.88
8 weeks	53.6	9.6	-25.24

The experimental result of proposed system is given in Table 3. It has been reported that the received power is reducing when observed after an apple samples. The observed mean value of the received power is used to evaluate the quality of an apple. The experimental observation indicates that, when an apple is at premature and mature stage; its dielectric constants as well as absorption of microwave power is increasing. Hence received power is reduced.

Fig. 8: Partially and highly rotten apple sample verified after testing.

From the experimental observations, an apple with partial rotten and highly rotten condition of an apple is determined. When an apple is partially rotten and highly rotten, the absorption in the apple is increased. The received power observed for this condition is in the range of -27.90 dB to -28.8 dB and for premature to mature it is -23.63dB to -25.05 dB. Fig. 8 shows the verified result of partially and highly rotten samples of an apple.

4. Conclusion

The conventional quality evaluation method considers exterior part of the fruit and it excludes interior part thus a non-invasive quality evaluation is necessary. The result of S11 of the developed transmitter and receiver antenna are -

24.98 dB, -12.65dB and the VSWR are 1.11, and 1.6 respectively. The variation in the result of simulation and developed antenna is due to material and precision in manufacturing process. The range of good condition and rotten condition apple has been recorded. The predicted result of the partially rotten apples is verified. If the range of S11 is -27.90 dB to -28.8 dB, then the apple is partially to highly rotten in condition and when the range of S11 is -23.63dB to -25.05 dB, an apple is in good condition. The observed efficiency of the proposed technique is 80-90%.

References

[1] Nelson, Stuart O. "Measuring dielectric properties of fresh fruits and vegetables." *Antennas and Propagation Society International Symposium*, IEEE, Vol. 4., 2003.

[2] Nelson, Stuart O. "Dielectric spectroscopy studies on fresh fruits and vegetables." *Antennas and Propagation Society International Symposium*, IEEE. Vol. 4, 2005.

[3] Nelson, Stuart O., Wenchuan Guo, and Samir Trabelsi. "Study of fruit permittivity measurements for quality detection." *Instrumentation and Measurement Technology Conference Proceedings*, IMTC 2008, IEEE, 2008.

[4] Nelson, Stuart O. "Dielectric spectroscopy of fresh fruits and vegetables." *Instrumentation and Measurement Technology Conference*, IMTC 2005. Proceedings of the IEEE. Vol. 1. 2005.

[5] Balanis, Constantine A. Antenna theory: analysis and design. John Wiley & Sons, 2016, pp 811-826.

[6] Majumder, Alak. "Rectangular microstrip patch antenna using coaxial probe feeding technique to operate in S-band." *International Journal of Engineering Trends and Technology* (IJETT) 4.4 (2013).

[7] Sreemathy, R., et al. "Design, Analysis and Fabrication of Dual Frequency Distinct Bandwidth Slot Loaded Wash Cotton Flexible Textile Antenna for ISM Band Applications." *Prog. Electromagn. Res. M* 109 (2022): 191-203.

[8] Nelson, Stuart O. "RF and microwave energy for potential agricultural applications." *Journal of Microwave Power*, 20.2 (1985): 65-70.

[9] Guo, Wenchuan, et al., "Maturity effects on dielectric properties of apples from 10 to 4500 MHz," *LWT-Food Science and Technology*, vol. 44, No.1, pp. 224-230, 2011.

[10] Gaikwad, Sandeep Vinayak, and Arun N. Gaikwad. "RF and Microwave Low Power Dielectric Heating Using Parallel Plate Applicator to Control Insect Pests on Tomato Plant." *Progress In Electromagnetics Research M* 49 (2016): 81-89.

[11] Ghanem, T. H., "Dielectric properties of liquid foods affected by moisture contents and temperatures," *Misr Journal of Agricultural and Engineering*, vol. 27(2), pp. 688-698, 2010.

[12] Koledintseva, Marina, et al. "Engineering of ferrite-graphite composite media for microwave shields." (2006): 598.Mane, P. B. et al. (2017). Watermarking and cryptography based image authentication on reconfigurable platform. Bulletin of Electrical Engineering and Informatics, 6(2), 181-187.

[13] Mandwale, A. J. et al. (2015, January). Different Approaches For Implementation of Viterbi decoder on reconfigurable platform. In 2015 International Conference on Pervasive Computing (ICPC) (pp. 1-4). IEEE.

[14] Mane, P. B., & Mulani, A. O. (2018). High speed area efficient FPGA implementation of AES algorithm. International Journal of Reconfigurable and Embedded Systems, 7(3), 157-165.

[15] Kashid, M. M et al. (2022, November). IoT-Based Environmental Parameter Monitoring Using Machine Learning Approach. In Proceedings of the International Conference on Cognitive and Intelligent Computing: ICCIC 2021, Volume 1 (pp. 43-51). Singapore: Springer Nature Singapore.

[16] Mr.Rahul S Pol, Prof M. Murugan, 'A Review on Indoor Human Aware Autonomous Mobile Robot Navigation Through a Dynamic Environment', International Conference on Industrial Instrumentation and Control (ICIC 2015), held by Government college of engineeing Pune, ICIC2015, 28th-30th May 2015, pp-987

[17] Dr. Rahul S Pol, Dr. B. Sheela Rani, Prof M. Murugan (2021). Optimal Path Planner for Indoor Mobile Robot Environment. Design Engineering, 8297-8309.

[18] Desai, N. ., & Shukla, P. . (2023). Performance of Deep Learning in Land Use Land Cover Classification of Indian Remote Sensing (IRS) LISS – III Multispectral Data. International Journal on Recent and Innovation Trends in Computing and Communication, 11(3), 128–134. https://doi.org/10.17762/ijritcc.v11i3.6329

[19] Ricci, A., Jankowski, M., Pedersen, A., Sánchez, F., & Oliveira, F. Predicting Engineering Student Success using Machine Learning Algorithms. Kuwait Journal of Machine Learning, 1(2). Retrieved from http://kuwaitjournals.com/index.php/kjml/article/view/118

[20] Kothandaraman, D., Praveena, N., Varadarajkumar, K., Madhav Rao, B., Dhabliya, D., Satla, S., & Abera, W. (2022). Intelligent forecasting of air quality and pollution prediction using machine learning. Adsorption Science and Technology, 2022 doi:10.1155/2022/5086622

Table 3: Experimental results at different condition of an apples

Apple conditions	Marked section and mean	Received power through an apple (dB)					
		Red Delicious			Joly Red		
		R1	R2	R3	J1	J2	J3
Premature	Section 1	-23.2	-24	-23.8	-25.1	-24	-24.1
	Section 2	-23.55	-23.2	-23.8	-24.8	-23.9	-24.8
	Section 3	-24	-24.5	-24	-24.8	-24.4	-23.8
	Section 4	-23.5	-23.1	-23.7	-25.8	-25.1	-24.1
	Average	-23.56	-23.7	-23.82	-25.12	-24.35	-24.2
	Mean	-23.69			-24.55		
Mature	Section 1	-25	-24.9	-24.9	-25.1	-25.2	-24.2
	Section 2	-25.1	-25.5	-24.2	-25.4	-24.7	-26.8
	Section 3	-24.3	-24.1	-25.5	-24.1	-25.2	-24.7
	Section 4	-24.5	-25.8	-24.4	-25.4	-24.8	-25.1
	Average	-24.72	-25.07	-24.75	-25	-24.97	-25.2
	Mean	-24.85			-25.05		
Mature but partially rotten internally	Section 1	-27.1	-27.3	-28.7	-26.9	-27.33	-26.8
	Section 2	-28.3	-28.8	-27.8	-26.6	-27.8	-26.45
	Section 3	-26.5	-28.4	-26.9	-27.1	-27.45	-27.51
	Section 4	-28.6	-28.2	-28.3	-27.7	-27.68	-27.99
	Average	-27.62	-28.17	-27.92	-27.07	-27.56	-27.18
	Mean	-27.90			-27.27		
Highly Rotten	Section 1	-28.32	-27.9	-28.95	-29.5	-29.6	-28.9
	Section 2	-28.8	-29.18	-28.6	-28.6	-28.9	-28.84
	Section 3	-29.6	-29	-28	-28.33	-28.8	-29.21
	Section 4	-28.71	-28.4	-28.8	-29.4	-27.96	-27.69
	Average	-28.85	-28.62	-28.58	-28.95	-28.81	-28.66
	Mean	-28.68			-28.81		