Application of Microwave signal for Non-invasive detection of adulteration in edible oil

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Abstract:

Microwave region lies within the frequency range of 3 GHz to 30 GHz of electromagnetic radiation. Microwave transmission towers and satellites allow broadcasting of television and radio, use of mobile phones, internet etc. Application of microwave signal is inevitable in defense sector as well as in medical sector for diagnosis and treatment. Monitoring of earth surface and atmosphere is also done by using microwave signal. Currently, material processing and manufacturing are carried out in industries like ripening, curing and drying of diverse materials with the use of microwave. Even, in home appliances, microwave signal is used in microwave oven for heating of food. Microwave signal is increasingly being used in recent studies to identify adulterants, contaminants and foreign particles in food. This study uses a non-invasive method to detect adulteration in pure edible oil both qualitatively and quantitatively. Pure oil and adulterated oil i.e., low-quality, inexpensive oil combined with pure oil—have different relative dielectric constants. As a result, the transmission coefficients and resonant frequencies of microwave signal through pure and adulterated oil will differ. In order to detect adulteration in pure oil, this feature is investigated.

Keywords: Adulteration, Microwave, Non-invasive method, Transmission coefficients.

1. Introduction:

Application of microwave signal in modern communication system like mobile phones, internet and Global Positioning System (GPS) have contributed inevitably in our recent fast-paced life style [1, 2]. It is presently used as a diagnostic imaging tool in medical sector like MRI, CT scan, Laser Surgery [3, 4]. Microwave signal is applied in RADAR system in domestic and defense aircrafts [5]. Recently, detection of adulterants or impurities in food products is also made possible by microwave signal. Numerous physical, chemical and biological methods have been developed till date to determine the presence and quantity of adulterants in food products [6]. However, most of the methods possess various disadvantages like requirement of skilled food analysts, expensive chemicals, sophisticated laboratory set up and equipment, high time consumption which are really tedious and difficult to access. Serious initiatives have been taken by Food Safety and Standards Authority of India (FSSAI) and other private agencies, concerned with food safety and public health to check the quality of different food items by establishing food testing laboratories and quality control laboratories [7-10]. But, the limitation of such amenities in metropolitan cities and urban areas leaves most of the rural and semi-urban areas under inconvenience.

The following proposed method is very convenient as the total system is portable and this test for detecting adulterants or impurities in food can be performed in packaged condition i.e., in non-invasive manner. In the previous year, in our research laboratory, successful precise detection of adulterants like small stones and broken rice quantitatively within pure rice was done by using microwave signal [11]. The shift in resonant frequencies of Reflection Co-efficient (S_{11}) of reflected microwave signal at a specific frequency range which arises due to variation in dielectric constants of pure rice grains and adulterated rice is used for this non-invasive detection. This process has been also applied for quality determination of other solid food items. But, in case of liquid food products, impurities or adulterants may be dissolved or present in colloidal forms or precipitated at the bottom. As a result, it becomes difficult to identify adulterants if present non-uniformly in liquid food.

Although, innovative physical methods (other than using expensive chemical reagents and complex biochemical procedures) of detection of adulterants in pure liquid food items have been developed, the simplicity and practical applicability of the procedures are still questionable. Wide dynamic range microwave planar coupled ring resonator for sensing applications has been developed as well as highly sensitive microwave sensors for measurement of fluid concentrations are designed for detection and sensing purposes [12, 13]. Also, high resolution identification method using Radio Frequency (RFID) for sensing liquid samples using a chipless tag has been discovered [14]. Even, recently a portable Real Time Microwave Milk Quality Monitoring Sensor is designed for determination of the quality of milk sample [15].

With a view to overcome the existing challenges, an attempt is made to determine the presence of adulterants in liquid food using similar experimental set up (with slight modifications) as described in [11] in our laboratory. In the present research work, two (2) different expensive brands of edible Sunflower Oil namely, (i) Sundrop Super Life Advanced and (ii) Saffola Gold (blend of Sunflower oil and Rice Bran oil) are considered as pure liquid food samples under test and two (2) different types of low-quality cheap edible oils of local brand namely, (i) Rapeseed oil and (ii) Palm oil having similar colour and appearance as compared to the pure Sunflower Oil are used as adulterants.

Edible oil has been selected as the experimental liquid food product as in present market condition, lots of incidents of using contaminated oil/ low-quality oil in shops, hotels and restaurants have been reported. Hydrogenated oils and fats contain long chain saturated fatty acids which helps in creation of trans fats. Trans fats are associated with elevated risks of cardiovascular diseases, higher levels of Low-Density Lipoprotein (LDL) i.e., bad cholesterol, and lower levels of High-Density Lipoprotein (HDL) i.e., good cholesterol. Therefore, non-hydrogenated oils are generally considered safer and healthier than their hydrogenated counterparts [16-21]. Oils that aren't hydrogenated include most of the plant-based oils (vegetable oils) especially sunflower oil, safflower oil, olive, avocado, canola oils which contain more monounsaturated and polyunsaturated fat that reduces LDL cholesterol levels when substituted for saturated and trans fats. In India and neighbouring countries, sunflower oil is mostly consumed as one of the healthiest and risk-free edible oils and hence two highly expensive brands of sunflower oil (Sundrop Super Life Advanced and Saffola Gold) are used as pure edible oil products in the experiments. Wholesale merchants as well as retailers add certain quantity of low-cost cheap edible oil within the expensive branded oil products for illegal monetary benefit. In order to prevent these kinds of malpractices and to ensure food safety, the innovation of novel techniques regarding non-invasive detection of impurities in expensive edible oils even in packaged conditions is the need of the hour.

This research work clearly discusses the detailed method for detection of presence of low-cost palm oil and rapeseed oil within costly branded pure sunflower oil non-invasively by the use of microwave signal.

2. Principle of the Experiment:

The study described here is based on the observation that the transmission properties of a material at microwave frequency range vary as its dielectric constant varies. In this paper, various kinds of pure edible oils are taken as the food products under test and different types of low-quality cheap edible oil are used as adulterants in separate experiments. Each different type of edible oil has a particular dielectric constant. The adulterated edible oil will have a difference in dielectric property as compared to the pure one. Hence, the transmission characteristics will be different. Based on this principle the pure forms of edible oils as well as any liquid food items can be distinguished from the adulterated forms.

3. Experimental Procedure:

A special experimental setup is prepared consisting of two vertical wooden stands which are connected with two thin horizontal wooden platforms as shown in Figure 1. Both the wooden platforms are clamped with the vertical stands and they can be adjusted to any height by using screws. When the two horizontal wooden platforms are adjusted to the same height, they leave a small space between them. The platforms can hold the plastic box containing pure or adulterated edible oil sample at any desirable height by means of adjustable screws. The plastic box taken for the experiment is filled with 200 ml of edible oil and kept on the platforms with its lid open. The transmitting antenna is fixed in a socket provided under the platform holding the box containing oil sample so that the incident microwave signal from the transmitting antenna travels through the space between the two discontinuous wooden platforms and reach the oil sample. The transmitted signal through the oil sample is captured by the receiving antenna which is kept hanging from the ceiling above the box containing the oil sample covering its aperture to capture the maximum amount of transmitted signal. Now the transmission co-efficient (S_{21}) i.e., the ratio of transmitted signal to incident signal is recorded in Vector Network Analyzer (VNA).

This entire procedure is repeated for measurement of transmission co-efficient of adulterated oil sample when low-quality cheap oil samples are mixed in fixed proportions with the pure edible oil samples. In this experiment, two (2) different expensive brands of Sunflower Oil namely, (i) Sundrop Super Life Advanced (manufactured by AgroTech Foods Ltd. bearing FSSAI License No. 10014047000183) and (ii) Saffola Gold (manufactured by A.P. Organics Limited bearing FSSAI License No. 10012063000100) are used as high quality pure edible oil samples and two (2) different types of cheap edible oils namely, (i) Rapeseed oil and (ii) Palm oil are used as adulterants. Therefore, four (4) different sets of experimental data are taken using all of these combinations of high quality and low-quality oil samples (adulterants). The specific ratios of adulterant (low-quality oil) to pure oil are taken from 1:100 (i.e., 1 ml of low-quality oil sample or adulterant present in every 100 ml of pure oil) to 30:100. The respective graphs of "Transmission Co-efficient (S_{21}) vs. Frequency" are plotted. The results are analysed and discussed in the later sections. The detailed structure of the experimental setup is shown in Figure 1.

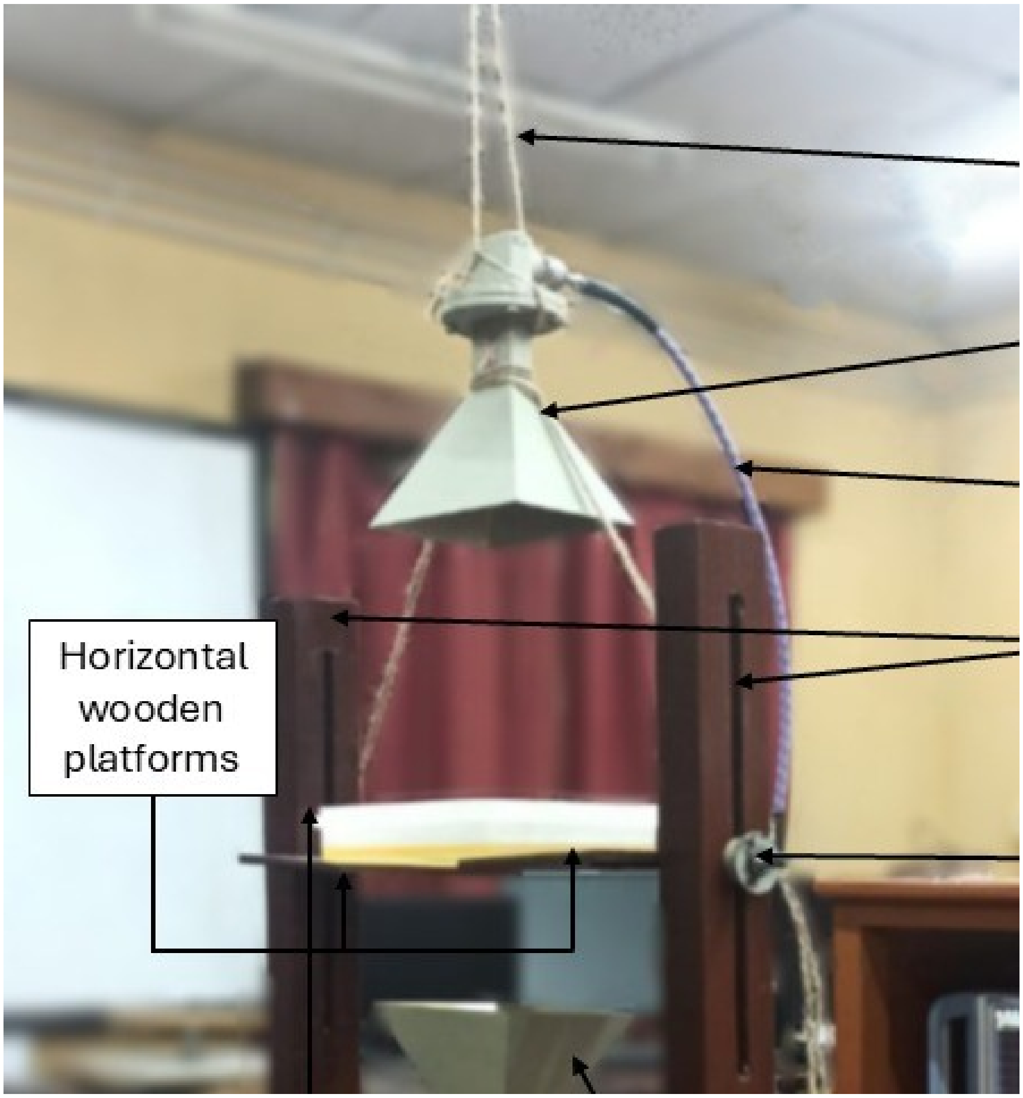
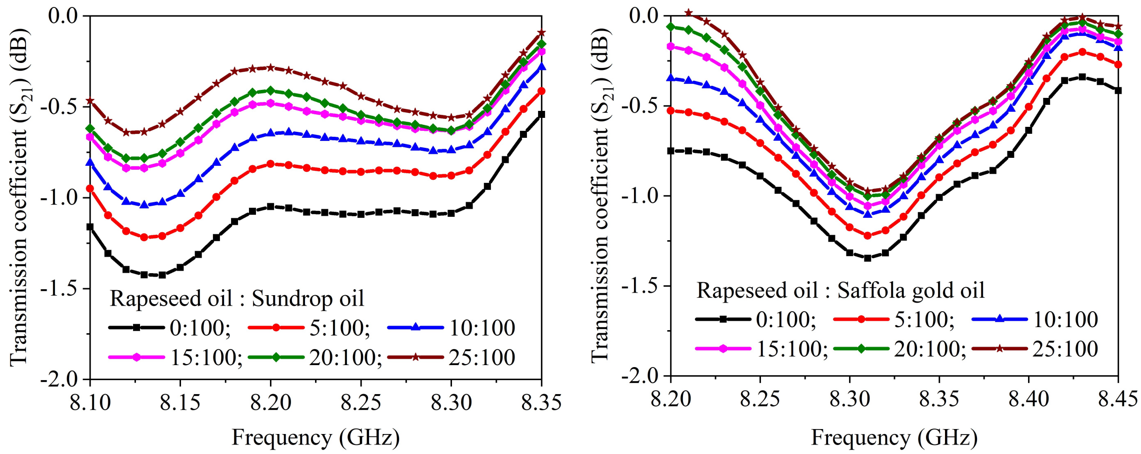


Figure 1: Experimental Set-up

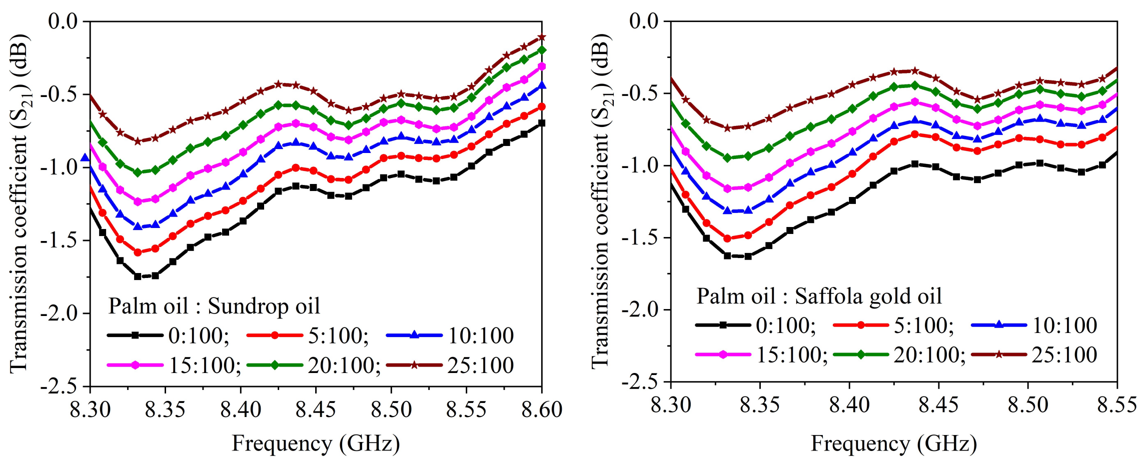
4. Results:

The experimental approach begins with measuring the transmission coefficient of pure Sundrop oil using a VNA. In the first stage of this experiment, rapeseed oil is used as an adulterant, and is blended with pure Sundrop oil in the ratios of 5:100 to 30:100. The transmission coefficient is measured and documented for each adulterant/pure oil ratio. The determined transmission coefficients of Sundrop oil with rapeseed oil as an adulterant are shown in Fig. 2(a). Rapeseed oil is then blended with pure Saffola Gold oil, and the prior ratio of adulterant to pure oil is used to calculate the measurement. Figure 2(b) depicts the transmission coefficient of Saffola Gold oil with rapeseed oil as an adulterant. From both figures, we can observe that as the rate of adulterant is increasing in pure oil, the magnitude of the transmission coefficients are also increasing.



(a) (b)

Figure 2: Transmission coefficient vs. Frequency of (a) Sundrop oil with Rapeseed oil as adulterant, (b) Saffola Gold oil with Rapeseed oil as adulterant.

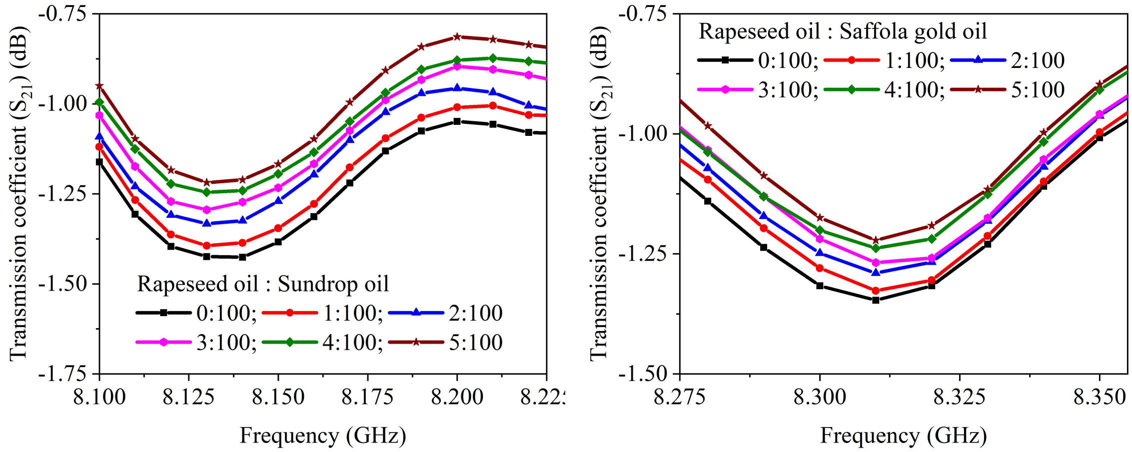


(a) (b)

Figure 3: Transmission coefficient vs. Frequency of (a) Sundrop oil with Palm oil as adulterant, (b) Saffola Gold oil with Palm oil as adulterant.

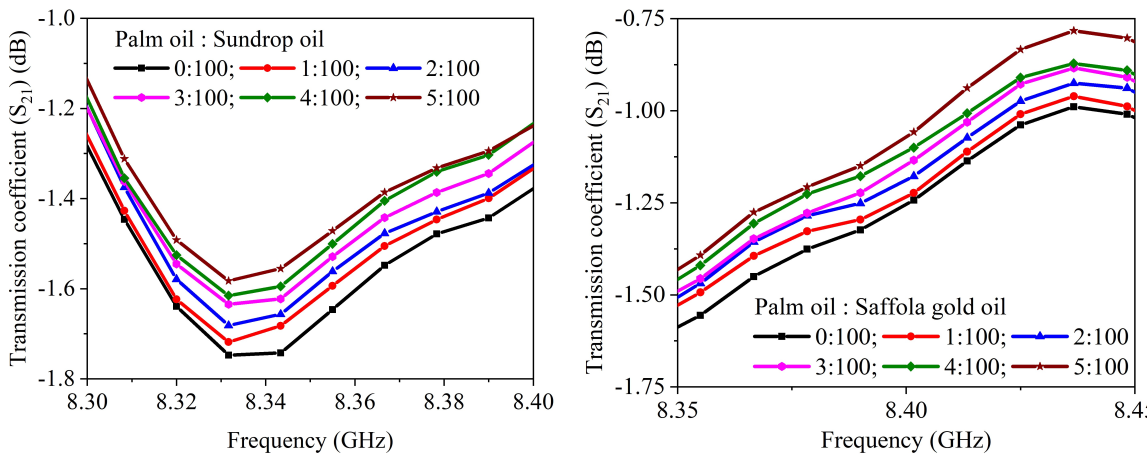
In the second stage of this experiment, palm oil is used as an adulterant alongside pure Sundrop oil and pure Saffola Gold oil. Figures 3(a) and 3(b) exhibit the transmission coefficient measurement results for Sundrop oil and Saffola Gold oil, which contain Palm oil as an adulterant. Similar increasing orders of transmission coefficients are observed with increasing rates of palm oil as an adulterant. Thus, this method can be used to detect adulterants in pure oil.

The experiment is also conducted to see whether the adulterant may be detected in micro amounts. The same approach is used to determine the transmission coefficient of Sundrop and Saffola Gold oil, which contains rapeseed and palm oil as adulterant. The adulterant is combined with pure oil at a ratio ranging from 1:100 to 5:100. Figures 4(a) and 4(b) show the measurement findings of transmission coefficients for Sundrop oil and Saffola Gold oil using rapeseed oil as an adulterant. Figures 5(a) and 5(b) exhibit the transmission coefficient measurement findings for Sundrop oil and Saffola Gold oil containing palm oil as an adulterant, respectively.



(a) (b)

Figure 4: Transmission coefficient vs. Frequency of (a) Sundrop oil with Rapeseed oil as adulterant, (b) Saffola Gold oil with Rapeseed oil as adulterant.



(a) (b)

Figure 5: Transmission coefficient vs. Frequency of (a) Sundrop oil with Palm oil as adulterant, (b) Saffola Gold oil with Palm oil as adulterant.

Similar results show that when the rate of adulterant in pure oil increases, so do the magnitudes of the transmission coefficients. Thus, the experiment technique can detect adulterants in pure oil in both macro and micro levels.

5. **Discussion:**

When Microwave signal is passed through a material, Transmission Co-efficient (S_{21}) and Resonant Frequency of the curve "Transmission Co-efficient (S_{21}) vs. Frequency (GHz)" depends upon some factors like dielectric constant (ϵ_r) of the material. Here, in the plotted curves, "Transmission Co-efficient (S_{21}) vs. Frequency (GHz)", the factor, "Transmission Co-efficient (S_{21})" has been considered for detection of adulterants in pure edible oil. Transmission Co-efficient (S_{21}) of the above-mentioned graphs depend upon the factor, "Dielectric constant (ϵ_r)" of the material. A particular dielectric constant is associated with each type of particular edible oil. Both high quality pure edible oil and low-quality cheap edible oil (adulterants) have different but specific values of dielectric constant. Therefore, when adulterants are mixed with pure oil, dielectric constant of the mixture will be modified. As a result, Transmission Co-efficient (S_{21}) of the respective curves for pure and adulterated oil samples will be different. Based on this property, detection of adulterants is possible in pure edible oil. By analysing the rise/ fall (increase/ decrease) of Transmission Co-efficient (S_{21}) at a particular range of frequency and comparing with previously established experimental results, prediction of the quantity of adulterant present in pure oil can also be done. Hence, both qualitative and quantitative detection of adulterated oil is possible using this novel experimental method.

6. **Conclusion:**

This method thus proved to be successful in detecting adulterants present in pure oil samples by analysing the respective upward and downward shifts in Transmission Co-efficient (S_{21}) at a specific frequency range. Even if low-quality cheap oil is present as adulterant in trace amount (1 ml adulterant in every 100 ml pure oil), this novel experimental procedure is able to detect it with high level of accuracy and precision. This process can have a very crucial industrial application. The modification of dielectric properties while passing microwave signal through materials with different dielectric properties provides the advantage of non-invasive detection (i.e., without opening the food package) of food quality. Hence, quality of packaged food can also be detected even after packaging and storing. In case of food testing laboratories, the quality of liquid food products (edible oil, milk and milk products, water, beverages etc.) can be easily checked by this method before sending food products for sale in the market. Deterioration of food due to improper packaging, transportation and storage conditions can thus be prevented and food safety can be enhanced while purchasing packaged food products from retail shops. So, the effectiveness of this approach and its benefit over earlier mentioned invasive methods of detection is shown. A prior knowledge of the nature of the curve of "Transmission Co-efficient (S_{21}) vs. Frequency" for different pure food items will assist in indicating the purity/ quality of the food being tested. Any change in the behaviour of the plot indicates the presence and quantity of adulterants in pure food products, which can be detected by proper interpolation and/or extrapolation of the respective curves. Expert food analysts are not needed for this process. The experiment's accuracy and precision can be increased by changing, enlarging, or narrowing the permitted frequency range of microwave signal. The process can be extended beyond food articles such as detection of percentage of components or impurities in crude petroleum, detection of quantity of any foreign elements in blood or other body fluids in medical diagnostic laboratories etc.

References:

[1] Shun-Yun Lin and Kuang-Chih Huang, "A compact microstrip antenna for GPS and DCS application," in *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 3, pp. 1227-1229, March 2005, doi: 10.1109/TAP.2004.842597.

[2] M. Khalily, O. Yurduseven, T. J. Cui, Y. Hao and G. V. Eleftheriades, "Engineered Electromagnetic Metasurfaces in Wireless Communications: Applications, Research Frontiers and Future Directions," in *IEEE Communications Magazine*, vol. 60, no. 10, pp. 88-94, October 2022, doi: 10.1109/MCOM.004.2200052.

[3] T. G. Abouelnaga, E K. I. Hamad, S. A. Khaleel and B. Beiranvand, "Defining Breast Tumor Location Using a Four-Element Wearable Circular UWB MIMO Antenna Array," *MDPI, Appl. Sci.*, vol. 13, no. 14:8067, 2023.

[4] C. Origlia, D. O. Rodriguez-Duarte, J. A. T. Vasquez, J. C. Bolomey and F. Vipiana, “Review of Microwave Near-Field Sensing and Imaging Devices in Medical Applications,” MDPI, *Sensors,* vol. 24, no. 14:4515, 2024, https://doi.org/10.3390/s24144515.

[5] A. E. Spezio, "Electronic warfare systems," in IEEE Transactions on Microwave Theory and Techniques, vol. 50, no. 3, pp. 633-644, March 2002, doi: 10.1109/22.989948.

[6] S. Bansal, A. Singh, M. Mangal, A. K. Mangal, S. Kumar, “Food adulteration: Sources, health risks, and detection methods. Critical Reviews,” in *Food Science and Nutrition,* vol. 57, no. 6, pp. 1174-1189, 2017, doi: https://doi.org/10.1080/10408398.2014.967834.

[7] C. Calories, “FSSAI Strengthens the Food Testing Infrastructure,” *World Food Regulation Review*; Burnham, vol. 26, Iss. 6, Nov. 2016.

[8] S. Shukla, R. Shankar, and S. P. Singh, “Food safety regulatory model in India,” *Food Control,* vol 37, pp. 401-413, 2014.

[9] A. Mishra, *et al.*, “Chapter-5 Boosting Food Safety Culture in India: Initiatives Taken by FSSAI,” *ADVANCES in NUTRITION,* vol. 67, 2020.

[10] S. K. Kurunthachalam, “Initiatives to Build Capacity in the Area of Food Safety and Analysis,” *Med chem (Los Angeles)*, vol. 7, e110, 2017.

[11] P. Sarkar, *et al.*, “Detection of adulterants in rice grains by the characteristics of reflection coefficient of the incident microwave signal,” *Journal of Electromagnetic Waves and Applications*, vol 38, issue 9, pp 989-999, 2024.

[12] M. H. Zarifi, M. Daneshmand, “Wide dynamic range microwave planar coupled ring resonator for sensing applications,” *Appl. Phys. Lett.*, vol. 108, 232906, 2016.

[13] A. M. Albishi, O. M. Ramahi, “Highly Sensitive Microwaves Sensors for Fluid Concentration Measurements,” *IEEE Microw. Wirel. Compon. Lett.,* vol. 4, pp. 287–289, 2018.

[14] M. H. Zarifi, M. Daneshmand, “High-resolution RFID liquid sensing using a chipless tag,” *IEEE Microw. Wirel. Compon. Lett.,* vol. 27, pp. 311–313, 2017.

[15] L. Iram, M. Y. Sandhu, A. K. M. Z. Hossain and S. Khan, "Portable Real Time Microwave Milk Quality Monitoring Sensor," *2023 9th International Conference on Computer and Communication Engineering (ICCCE)*, Kuala Lumpur, Malaysia, pp. 167-172, 2023.

[16] Dupont, Jacqueline, Pamela J. White, and Elaine B. Feldman. “Saturated and hydrogenated fats in food in relation to health.” *Journal of the American College of Nutrition* 10.6 (1991): 577-592.

[17] B. Souad, “Hydrogenated oils and public health: a scientific analysis of trans fats and disease.” *Brazilian Journal of Health Review*, vol. 7, no. 9: e74771, 2024.

[18] F. A. Kummerow, “The negative effects of hydrogenated trans fats and what to do about them,” *Atherosclerosis*, vol. 205.2, pp. 458-465, 2009.

[19] D. Mozaffarian, and R. Clarke, “Quantitative effects on cardiovascular risk factors and coronary heart disease risk of replacing partially hydrogenated vegetable oils with other fats and oils,” *European journal of clinical nutrition,* vol. 63, no. 2: S22-S33, 2009.

[20] V. Dhaka, *et al.*, “Trans fats—sources, health risks and alternative approach-A review,” *Journal of food science and technology,* vol. 48, pp. 534-541, 2011.

[21] S. K. Gebauer, *et al.* “Vaccenic acid and trans fatty acid isomers from partially hydrogenated oil both adversely affect LDL cholesterol: a double-blind, randomized controlled trial,” *The American journal of clinical nutrition,* vol. 102, no. 6, pp. 1339-1346, 2015.