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Investigation of Animal Fats Using Microwave Non-Destructive Testing at X-Band

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***Abstract*— The ability to differentiate and identify different sources of oils and fats is vital, especially in specialized food products. Adulteration of vegetable oils with the lower cost animal fats in halal foods has become a major concern to consumers. This paper describes the application of the Microwave Nondestructive Testing (MNDT) method in the range of frequency from 8 GHz to 12 GHz. The MNDT is used to investigate the S-parameters for three types of animal fats which are chicken, beef, and goat. MNDT method is used due to its non-intrusive ability toward material under testing (MUT), and high-resolution characteristic. The experimental findings demonstrate S-parameter measurements of samples represented as complex reflection coefficient and complex transmission coefficient. The finding shows that animal fat had varying reaction toward microwave frequency for the X-band range based on its fluctuation in amplitude and phase of the frequency domain response. The results indicate that X-band microwave frequencies can be used to differentiate the different type and form of animal fats which are raw, baked, and oil.**

***Index Terms*—MNDT, Microwave, Waveguided, Animal fat**

I. Introduction

CHOCOLATE is a practically unique food in that it is solid at room temperature yet melts quickly on the tongue. This is because the major fat in it, cocoa butter, solidifies at temperatures below 25 degrees Celsius, holding all the solid sugar and cocoa particles together. The EU legislation (Directive 2000/36/EC) allows the substitution of cocoa butter with a maximum of 5% vegetable fats in chocolate products such as chocolate, milk chocolate, family milk chocolate, white chocolate, filled chocolate etc. (EU Monitor, 2000). Different countries have varying legislation regarding the amount of cocoa butter substitution in chocolate products but only vegetable fats are permitted to be used. Lard is one of the cheapest and most widely accessible fat in the food industry.In several countries, adulteration of lard with vegetable fats in food products such as chocolate still occurs because it is easily obtainable, and lower in price thus minimizing production costs [1].

Obtaining halal food is an obligation for Muslims. Halal food refers to food that is permissible according to Islamic law. Pork is prohibited for Muslims [2]–[4] and some non-Muslims prefer pork-free food due to health reasons. As the world's population rises, so does the Muslim community, therefore increasing the demand for halal products. In the case of non-intentional cross-contamination or intentional adulteration of fats, Muslims were enraged when the Malaysian Health Ministry announced that pig DNA had been found in Cadbury's products[5]. The Malaysian Scholars Association's secretary-general has called for a nationwide boycott of Cadbury products until the company can guarantee that not only one, but all of its products are free of pork DNA [6].

There are various modern approaches for halal detection [1], [7]–[11], but the methods involve mixing the sample with a chemical solution to modify the sample's state which is a destructive technique. There was a nondestructive way, but the identifying element was left up to the human, which is shown in many experiments. In another studies, artificial intelligence has shown its capability to outperforme humans [12] when on best condition [13].

Microwave Nondestructive Testing (MNDT) is another technique that has been studied to characterize food. It is a technique for determining the S-parameter of a sample. MNDT is an excellent approach since it is a non-intrusive method that does not modify the sample or measure the sample in a non-direct manner. For material testing, MNDT is a critical science that comprises the development of sensors and probes and processes and calibration methodologies for detecting faults, fractures, and moisture content using microwaves [14]. The method has been extensively researched in other disciplines, such as civil engineering, where most of the study has focused on concrete [15], [16]. In food technology, researchers have utilized MNDT to characterize fruit states to evaluate their ripeness [17]. The MNDT characterization approach has also been used to examine liquids like oil [18] and animal fats [19]. Analysis of animal fats using MNDT was previously conducted using a portable probe with a high-frequency band however, they did not investigate the effect of various heating times on the S-parameters of the fats [19].

This paper aimed to investigate three sources of animal fats

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(chicken, beef, and goat) in the form of raw, baked and oil using MNDT at X-band. The step-by-step process of measuring and analyzing the S-parameters of samples was described in detail. The effects of different heating times on the animal fat characteristics were measured and discussed .

II. Methodology

Figure 1 shows the process of analyzing the animal fats characteristics measured using MNDT. The MNDT equipment used in this experiment was calibrated first to ensure the data collected was up to standard and within the theoretical calculation. The data from the MNDT equipment was then collected and transferred to a personal computer for analysis. For clean and easy-to-take data for downstream data analyses, the raw data was converted to a spreadsheet using Microsoft Excel software.

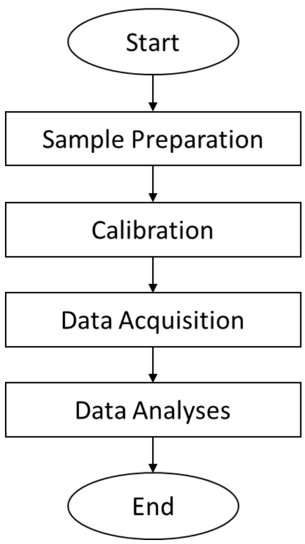

Figure 1: The step by step process of the experiment

A. Sample preparation

The chicken, beef, and goat raw fats were cut into 5 cm long, 5 cm wide, and 0.5 cm high slices to ensure that each sample had the same exposure surface area and depth. The samples were separated into three groups: raw sample (see Figure 2), baked sample (see Figure 3) and oil.

The baked samples were heated for 10 minutes and 15 minutes at 225^{o}C to create 10-minute and 15-minute baked fats and oils. These time variations were selected to investigate the effect of various heating times on the S parameters of the samples. The 225^{o}C temperature was chosen as this temperature lies within the standard heating temperature range of goat and cow fat with a shorter heating time [20].

The arrangement of the MNDT equipment used in this study is shown in Figure 4. Two spot-focusing horn antennas were connected to a vector network analyzer (VNA). The equipment was calibrated before each measurement was taken to ensure that the S-parameters are within theoretical limits. The S-parameters are the data to be collected, which consists of complex reflection coefficient (S_{11}) and complex transmission coefficient (S_{21}).

Figure 2 : Samples of raw chicken

Figure 3 : Samples of baked chicken

B. Calibration

The procedure described in [20] was implemented in the calibration process. Using three standards which are a through connection, a short circuit connected to each port (Reflect) and a transmission line connected between test ports, the S_{11} and S_{21} parameters were measured. The observed amplitude and phase of the complex transmission coefficient (S_{21}) for the through connection are 0.05 dB and 0.2° respectively which meet the standard requirements. The frequency measurements of the samples were in the range of 8 GHz to 12 GHz. A Teflon metal plate (15.4 cm × 15.4 cm × 0.2 mm) was then placed on a sample holder at the reference plane to perform the reflect calibration technique. It was observed that the amplitude and phase of the complex reflection coefficient (S_{11}) are 0.2 dB and 1 degree which are within the standard value (Reflect).

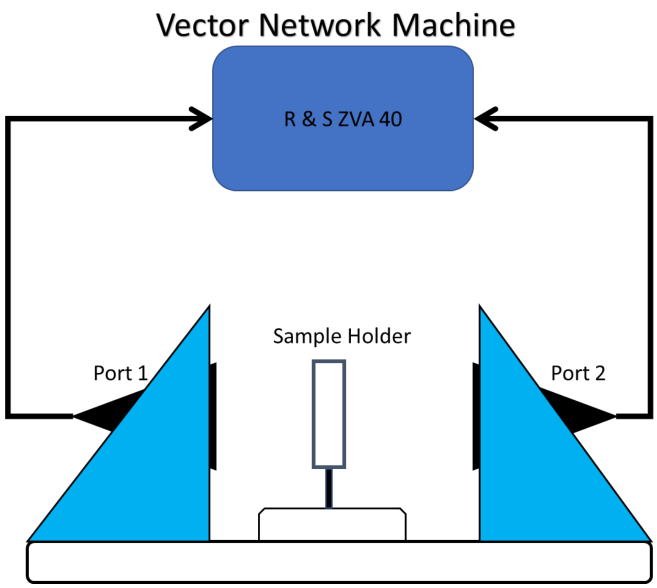

Figure 4: The arrangement of the MNDT system for the S-parameters measurement.

C. *Data acquisition*

The data acquisition was carried out using an open-end coaxial cable sensor and the vector network analyzer as the device that converts the analogue signal to a digital signal before the signal is transferred to file to the computer with data acquisition software for signal analysis. The raw and baked animal fats; chicken, beef and goat and their oils were first placed in the sample holder (see Figure 5). Then the S-parameters; S_{11} and S_{21} for each sample were measured over a frequency range of 8-12 GHz (X-band).

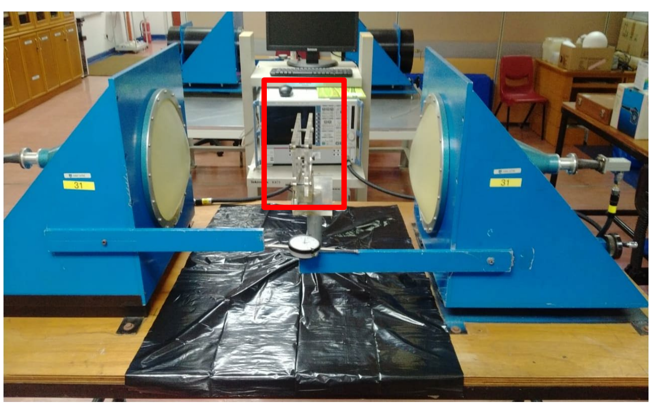

Figure 5: Diagram showing the sample holder (red box) used in the measurement.

D. Data analysis

In the analysis stage, the S-parameter data from each animal fat were divided into four types; raw fat, 10-minute baked fat, 15-minute baked fat and oil. A program written in MATLAB was developed to produce S_{11} and S_{21} plots of each animal fat type. The changes of the S_{11} and S_{21} of each animal fat type with the frequency were then examined and analyzed through observation [21], [22].

III. Results And Discussion

Figure 6 depicts a graph of the reflection coefficient (S_{11}) from raw chicken, raw goat, and raw beef. The amplitude of S_{11} demonstrates the comparison of animal fats. Uncooked chicken has the highest S_{11} amplitude. The goat and beef S_{11} exhibit a significant frequency variation from 8.5 GHz to 10.5 GHz before settling at 11 GHz. The amplitude of both goat and beef S_{11} drops at 8.6 Hz due to the frequency transmitted from S1 reaching the sample's resonance frequency. The S_{11} of the raw chicken fat shows practically no abrupt changes to the transmitted power from source 1, and the reflection coefficient can be said to remain constant over the entire X band.

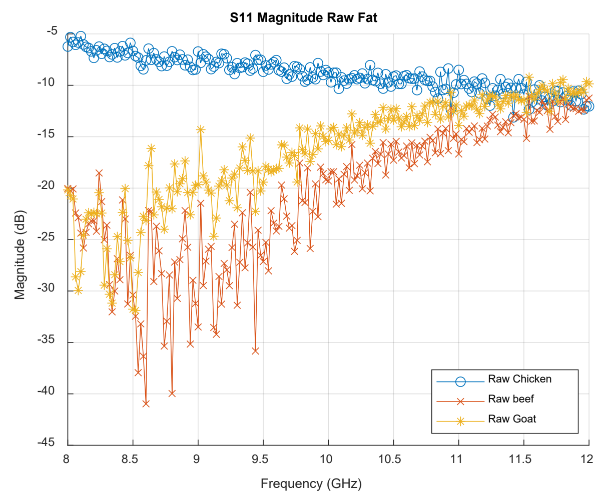

Figure 4: The reflection coefficient (S_{11}) of raw animal fats.

Figure 7 shows the complex transmission coefficient (S_{21}) of raw animals' fat**.** The plot showed the descending trend of S_{21} amplitude for all raw fat samples when the frequency is increased. This indicates that the S_{21} amplitude of raw fat is indirectly proportional to frequency. Raw goat exhibits the greatest variation in S_{21} amplitude among the three fats, whereas raw chicken and raw beef fats have a similar trend of S_{21} changes. This result shows that the loss of energy being transferred increases for all samples as the frequency increases. As the frequency increases, the level of energy being absorbed increases, which reduces the energy being received at port 1 from port 2. The S_{21} values of the three raw animal fats are distinct from 8 GHz to 12 GHz, therefore the identification can be made throughout the X-band.

Figure 8 shows the complex reflection coefficient (S_{11}), of samples that were baked for 10 minutes in the oven. The S_{11} amplitude of 10-minute chicken and goat fats were inversely proportional to the frequency, The 10-minute baked chicken and goat fat show similar inclination in S_{21} amplitude changes throughout the entire X-band spectrum. The changes in S_{21} amplitude are in a downward trend between 8.2 GHz and 9.7 GHz and remain stable from 10.25 GHz to 15 GHz for all three samples. The S_{11} values of the 10-minute baked chicken and goat fats can be easily identified throughout the X-band, except from 9 GHz to 10.25 GHz where the S_{11} values have a narrow gap.

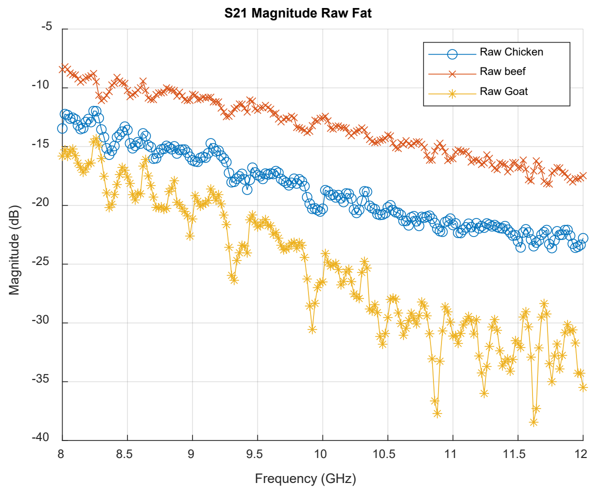

Figure 5: The transmission coefficient (S_{21}) of raw animal fat.

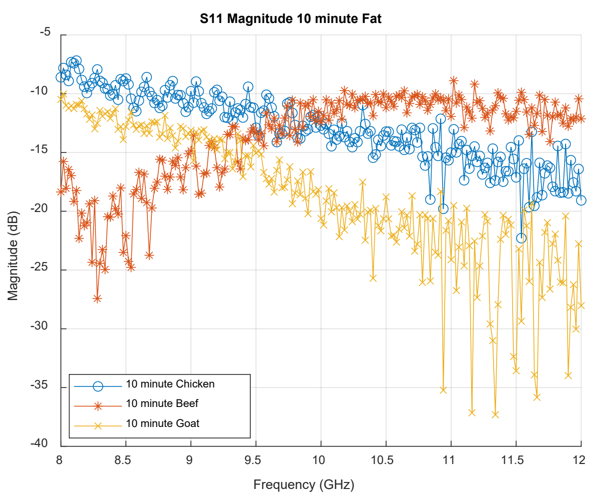

Figure 6: The reflection coefficient (S_{11}) of 10-minute baked animal fats.

Figure 9 shows the comparison of the complex transmission coefficient (S_{21}) of the 10-minute baked animal fats, with the S_{21} values of 10-minute baked beef fat having the lowest energy absorption compared to those of 10-minute baked chicken and goat fats. The S_{21} values of 10-minute baked chicken and goat fats have significantly greater energy absorption, with both having equal amplitude differences between 8 GHz and 12 GHz. The amplitude decreases as the frequency increases, but the amplitude does not fluctuate significantly, indicating that the sample had an insignificant reaction throughout the X-band frequency range.

Figure 10 depicts the complex reflection coefficient (S_{11}) plots of the 15-minute baked animal fats. The S_{11} amplitude of the chicken decreases as the frequency increases. The changes in the S_{11} amplitude of the 15-minute baked goat fat show that the sample has lower reflection with a large reaction toward the frequency being transmitted. This is because the 15-minute baked goat fat absorbs more energy compared to beef and chicken fat. The 15 minute baked beef fat has greater energy absorption at the early X-band frequency and the absorption decreases starting from 8.5 GHz, which implies that the energy at the higher frequency being reflected towards the antenna port increases.

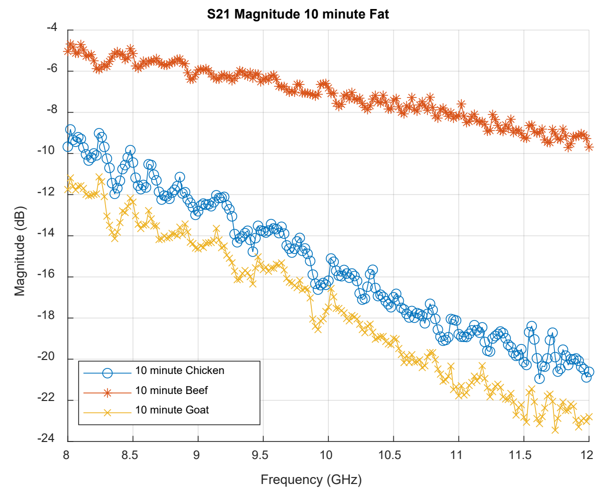

Figure 7: The transmission coefficient (S_{21}) of 10 minutes of baked animal fat.

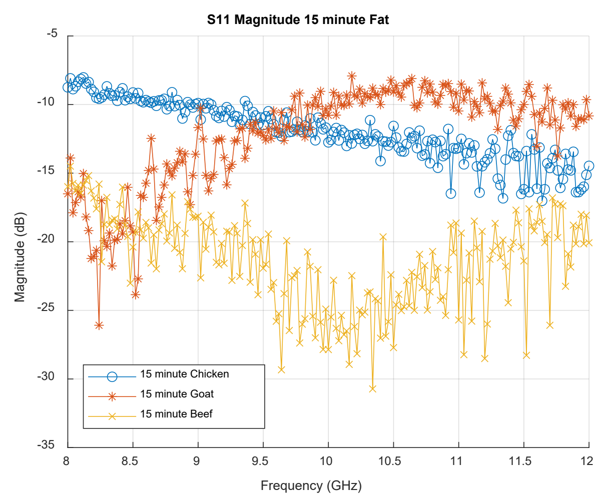

Figure 8: The reflection coefficient(S_{11}) of 15-minute baked animal fats.

Figure 11 shows the transmission coefficient (S_{21}) plots of the animal oils. The beef oil has the lowest energy absorption, followed by the goat and chicken oils. Both samples of the goat and chicken oils have similar S_{21} readings from 8 GHz to 9.1 GHz. The absorption was similar at this frequency before the large differences showed after 9.1 GHz. All the samples show no drastic changes in the S_{21} amplitude as the frequency being transmitted through them increases. It shows that the beef oil has large differences in S_{21} amplitude compared to those of the chicken and goat oils, while the chicken and goat oils have almost similar S_{21} values in early X-band frequency and get further apart as frequency increases.

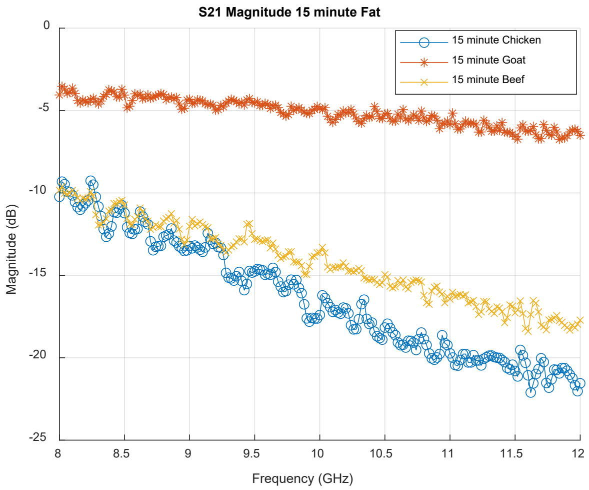

Figure 9: The transmission coefficient (S_{21}) of the animal oils

Figure 12 shows the reflection coefficient (S_{11}) waveforms of the beef fat in the form of raw, baked fat and oil. The S_{11} waveform of the beef oil has the resonance frequency at 10.06 GHz, at which the beef sample absorbs the highest energy of transmitted signal as a result, the reflected coefficient decreases as the frequency approached the resonance frequency and then increases when the frequency is higher than the resonance frequency. The S_{11} waveform of the beef raw fat has fluctuation before the frequency reaches 9.88 GHz. The S_{11} waveforms of the baked beef fat had the same patterns with fluctuation at 8.25 GHz which is the resonance frequency. The S_{11} amplitude of all beef samples increases after its resonance frequency until it reaches a point where there is no further reaction from the samples.

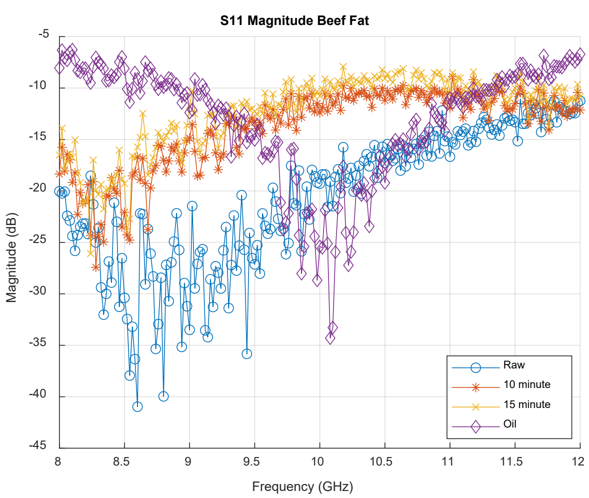

Figure 10: The reflection coefficient(S_{21}) of beef fat: Raw, baked, and Oil state.

Figure 13 shows the S_{21} waveforms of the raw beef fat, baked fat and oil. It demonstrates that oil has the lowest energy absorption than raw and baked fats, and raw fat absorbs the most energy than other fats and oil. The S_{21} of the beef baked fats shows that the solid-state changes of the fat cause less energy to be absorbed by the samples. The 15-minute beef baked fat absorbs less energy than that of 10-minute beef baked fat.

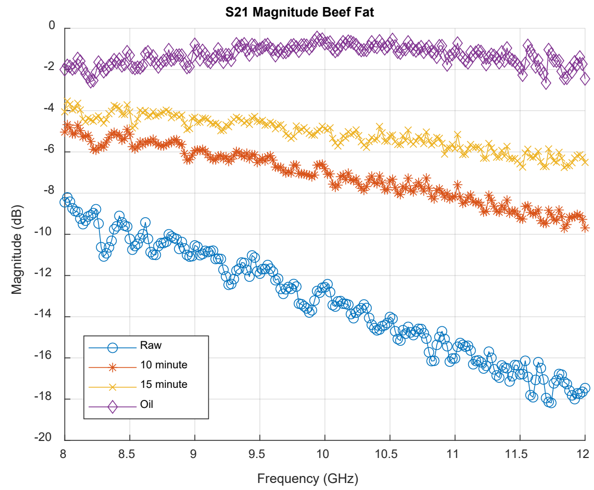

Figure 11: The transmission coefficient (S_{21}) of beef fat: Raw, baked, and Oil state.

For chicken fat samples, its oil absorbs a lot of energy compared to raw and baked fats as shown in Figure 14. The chicken oil resonance frequency is at 9.5 GHz. The S_{11} waveforms of the raw, 10 minute and 15-minute chicken fats are close to each other starting from 8 GHz to 10 GHz before separating, indicating that the three samples do not react very much with the transmitted signal at the beginning but react well only after 10 GHz.

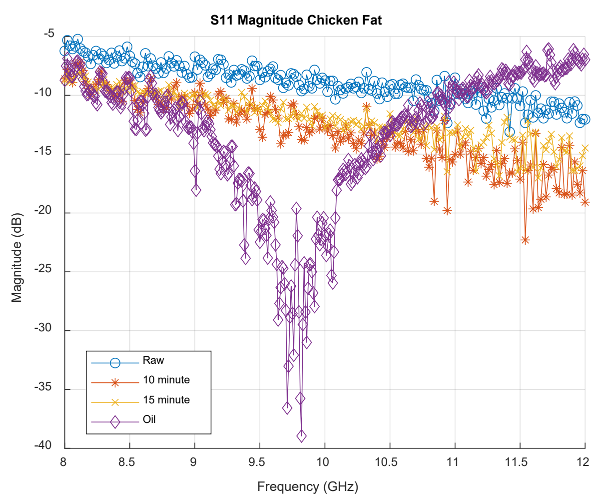

Figure 12: The reflection coefficient (S_{11}) of chicken fat: Raw, baked, and Oil state.

Figure 15 shows the transmission coefficient (S_{21}) waveforms of the chicken raw fat. baked fat and oil. the chicken oil S_{21} waveform is almost a straight line compared to those of dried and raw fats indicating that it does not react as the frequency increases. The three samples (raw fat, 10-minute, and 15-minute baked fats) had an increase in energy absorption when the frequency is increased. The fluctuation in the S_{21} waveforms of the chicken raw and baked fats can be seen at the same frequencies.

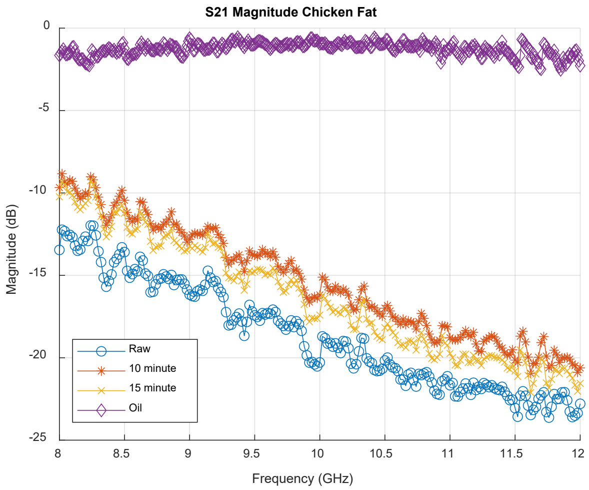

Figure 13: The transmission coefficient (S_{21}) of chicken fat: Raw, baked, and Oil state.

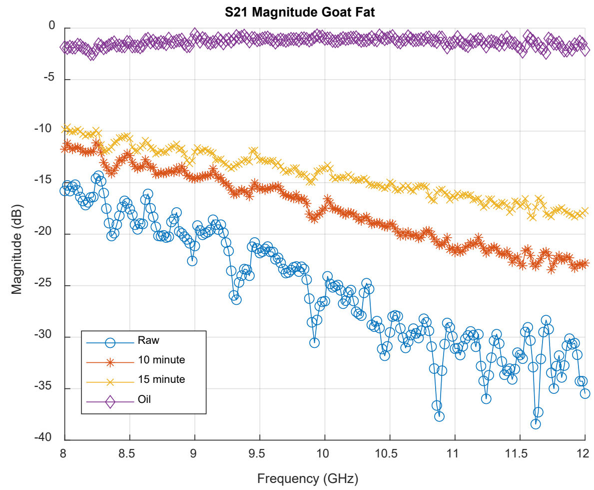

Figure 15: The transmission coefficient (S_{21}) of goat fat: Raw, baked, and Oil state.

Figure 16 shows the reflection coefficient (S_{11}) waveforms of the raw goat fat, baked and oil forms. The S_{11} amplitude of the goat oil decreases and increases rapidly compared to those of other goat fats. The minimum value of the S_{11} amplitude of the goat oil can be observed at the resonance frequency of 9.6 GHz. The magnitude of the 10 minute and 15-minute decreases in amplitude indicated the energy being transmitted to the receiver port of 2 being lower as the frequency increased as clearly seen from 8 GHz to 12 GHz in Figure 15.

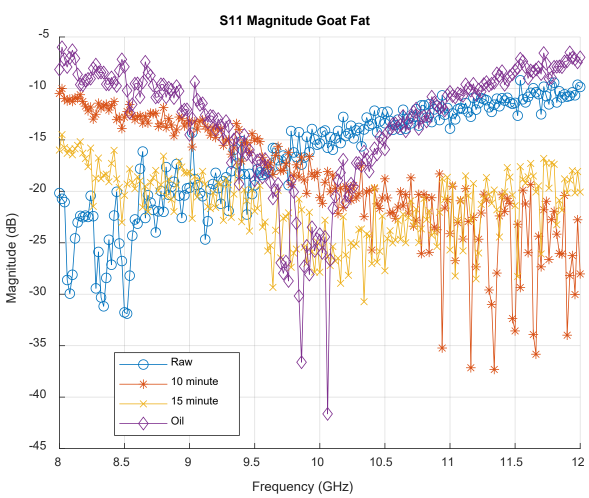

Figure 14: The reflection coefficient (S_{11}) of goat fat: Raw, baked, and Oil state.

Similar to other animal oils, the transmission coefficient (S_{21}) waveforms of the goat oil are almost a straight line compared to those of its raw and baked fats which indicates that it does not have a significant reaction as the frequency increases. The S_{21} of the 10-minute and 15-minute baked fat show a consistent change in the amplitude from 8 GHz to 12 GHz. The raw fat sample has the lowest S_{21} among all samples. The fluctuation can be seen in the S_{21} of the 10-minute and 15-minute baked fats at the same frequency.

Results from this experiment demonstrate the differences in Figure 7 for raw fat, Figure 11 for baked fat, and Figure 14 for baked fat show that the S_{21} can be recognized easily. Even though the S_{21} of chicken fat and baked fat is more like the goat in the same category, but they may still be distinguished. All raw fats absorb a lot of energy, which leads to a big drop in S_{21} values as the frequency rises, and the amount of energy absorbed decreases in baked form and even lower in oil form, which is due to higher raw fat in the baked fat sample dissolving into the oil.

IV. Conclusion

This study uses a microwave nondestructive testing approach to investigate the feasibility of utilizing the MNDT technique to provide clear and distinct features of chicken, beef and goat in the form of raw , baked , and oils. The S parameters of chicken, beef and goat fat samples were measured at an X-band microwave frequency. The analysis of the S parameters behaviour of the animal fats demonstrates that the S_{11} and S_{21} provide significant features of the animal fats, thus MNDT can be used to distinguish the fat types and states. However, other parameters such as dielectric properties must be considered in differentiating the animal fats that have close values of S-parameters.

V. Acknowledgement

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References

[1] Y. B. Che Man, Z. A. Syahariza, M. E. S. Mirghani, S. Jinap, and J. Bakar, “Analysis of potential lard adulteration in chocolate and chocolate products using Fourier transform infrared spectroscopy,” *Food Chemistry*, vol. 90, no. 4, pp. 815–819, May 2005, doi: 10.1016/j.foodchem.2004.05.029.

[2] Y. S. Lon and F. Widyawati, “Food and local social harmony: Pork, communal dining, and muslim-Christian relations in Flores,

Indonesia," *Studia Islamika*, vol. 26, no. 3, pp. 445–474, 2019, doi: 10.36712/sdi.v26i3.9917.

[3] M. Y. Musdja, "The risks of consuming haram food from medical perspectives," *Malaysian Journal of Consumer and Family Economics*, vol. 21, no. Special Issue 2, pp. 132–143, 2018.

[4] N. Hacioğlu, "Evaluation of hadīth narratives related with the animals whose meat is forbidden to eat," *Cumhuriyet Ilahiyat Dergisi*, vol. 22, no. 2, pp. 1191–1220, 2018, doi: 10.18505/CUID.492288.

[5] C. Z. Yu and T. J. Chan, "Cadbury Malaysia Porcine DNA Case: Lessons from Crisis Management and Cultural Perspectives," *Malaysian Journal of Social Sciences and Humanities (MJSSH)*, vol. 5, no. 8, pp. 33–38, 2020, doi: 10.47405/mjssh.v5i8.456.

[6] The Guardian, "Pork in Cadbury's: Malaysian chocolate recalled after DNA traces found | Cadbury | The Guardian," pp. 7–9, 2014, [Online]. Available: https://www.theguardian.com/business/2014/may/28/pork-in-cadburys-malaysian-chocolate-recalled-after-dna-traces-found

[7] S. N. Jha *et al.*, "Measurement techniques and application of electrical properties for nondestructive quality evaluation of foods-a review," *Journal of Food Science and Technology*, vol. 48, no. 4. pp. 387–411, Aug. 2011. doi: 10.1007/s13197-011-0263-x.

[8] A. A. Aziz, F. N. M. Nordin, Z. Zakaria, and N. K. Abu Bakar, "A systematic literature review on the current detection tools for authentication analysis of cosmetic ingredients," *Journal of Cosmetic Dermatology*. 2021. doi: 10.1111/jocd.14402.

[9] M. H. Yuswan *et al.*, "Hydroxyproline determination for initial detection of halal-critical food ingredients (gelatin and collagen)," *Food Chemistry*, vol. 337, no. August 2020, 2021, doi: 10.1016/j.foodchem.2020.127762.

[10] J. Čapla *et al.*, "Procedures for The Identification and Detection of Adulteration of Fish and Meat Products," *Potravinarstvo Slovak Journal of Food Sciences*, vol. 2020, no. 14, pp. 978–994, 2020, doi: 10.5219/1474.

[11] Y. S. Kim, H. K. Yu, B. Z. Lee, and K. W. Hong, "Effect of DNA extraction methods on the detection of porcine ingredients in halal cosmetics using real-time PCR," *Applied Biological Chemistry*, vol. 61, no. 5, pp. 549–555, 2018, doi: 10.1007/s13765-018-0389-x.

[12] T. Orosz *et al.*, "Evaluating human versus machine learning performance in a legaltech problem," *Applied Sciences (Switzerland)*, vol. 12, no. 1, Jan. 2022, doi: 10.3390/app12010297.

[13] M. Saveski, E. Awad, I. Rahwan, and M. Cebrian, "Algorithmic and human prediction of success in human collaboration from visual features," *Scientific Reports*, vol. 11, no. 1, Dec. 2021, doi: 10.1038/s41598-021-81145-3.

[14] D. K. Ghodgaonkar, V. v. Varadan, and V. K. Varadan, "Free-Space Measurement of Complex Permittivity and Complex Permeability of Magnetic Materials at Microwave Frequencies," *IEEE Transactions on Instrumentation and Measurement*, vol. 39, no. 2, pp. 387–394, 1990, doi: 10.1109/19.52520.

[15] H. Saad, H. A. Rahman, N. F. Nani, M. H. bin Mohd. Nasir, I. Pasya, and Z. Awang, "Simulation of Microwave Non Destructive Testing environment (MNDT) in determining the dielectric constant of concrete using waveguide port approximation at 8-12GHz (X-band)," in *2011 IEEE International RF and Microwave Conference, RFM 2011 - Proceedings*, 2011, pp. 83–86. doi: 10.1109/RFM.2011.6168701.

[16] A. Wahab, M. M. A. Aziz, A. R. M. Sam, K. Y. You, A. Q. Bhatti, and K. A. Kassim, "Review on microwave nondestructive testing techniques and its applications in concrete technology," *Construction and Building Materials*, vol. 209. Elsevier Ltd, pp. 135–146, Jun. 10, 2019. doi: 10.1016/j.conbuildmat.2019.03.110.

[17] M. F. A. Khalid, A. S. Ramli, N. H. Baba, and H. Saad, "A Novel Preliminary Study on Microwave Characterization of Siamese Mangoes Ripeness at K-Band," *IEEE*, vol. 4, 2008.

[18] N. A. Omar, M. A. Nazri, S. S. Alam, and M. H. Ali, "Consumer retaliation to halal violation incidents: The mediating role of trust recovery," *Jurnal Pengurusan*, vol. 51, no. 2017, pp. 101–113, 2017, doi: 10.17576/pengurusan-2017-51-09.

[19] K. Y. Sin and M. C. Sin, "Distinguished identification of halal and non-halal animal-fat gelatin by using microwave dielectric sensing system," *Cogent Engineering*, vol. 6, no. 1, Jan. 2019, doi: 10.1080/23311916.2019.1599149.

[20] N. E. Bengtsson, B. Jakobsson, and M. Dagerskog, "COOKING OF BEEF BY OVEN ROASTING: A STUDY OF HEAT AND MASS TRANSFER."

[21] N. A. M. Affendi, N. A. L. Alias, Z. Awang, M. T. Ali, and A. Samsuri, "Microwave non-destructing testing of rubber at X-band," *RFM 2013 - 2013 IEEE International RF and Microwave Conference, Proceedings*, pp. 333–337, 2013, doi: 10.1109/RFM.2013.6757279.

[22] H. Zhang and S. Kidera, "Polarimetric signature CNN based complex permittivity estimation for microwave non-destructive testing," *2020 International Symposium on Antennas and Propagation, ISAP 2020*, pp. 781–782, 2021, doi: 10.23919/ISAP47053.2021.9391236. EU Monitor (2000), https://www.eumonitor.eu/9353000/1/j9vvik7m1c3gyxp/vhckn6deunyz. Accessed on 14th May 2022.