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Corresponding Author: Dr. Syah Alam
Target Journal: Others
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Assoc. Prof. Syah Alam S Pd, MT, PhD <syah.alam@trisakti.ac.id>

PIER Journals Revision Request: 25010701.

1 message

PIER Editorial and Production OFFICE <noreply@service.jpier.org.cn> Wed, Feb 5, 2025 at 9:16 AM
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Dear Dr. Syah Alam:

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Title: Close Quarters Permittivity Detection Based on Tagging Antenna Sensor for Solid Material Characterization
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Reviewer 1's Comments:
1- The quality of the figures presented in the article should be improved to make them easily readable.
2- Normally, FR-4 substrate has dielectric losses that are not negligible at high frequencies, which degrades the performance of the sensor antenna. Why was this material chosen rather than a low-loss substrate?

3- Could the technique presented in this paper be used for high permittivity detection?
4- Could the technique presented in this paper be used for permittivity detection of materials with considerable dielectric losses?

Reviewer 2's Comments:
comments in file.
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Reviewer 3's Comments:
This study introduces a novel antenna sensor for permittivity detection of solid materials, leveraging resonance frequency shifts to determine permittivity through polynomial curve fitting. The proposed sensor achieves a high accuracy of 96% (Table 2) but exhibits limited sensitivity due to suboptimal E-field concentration. Validation against probe sensors demonstrates its potential for biomedical, pharmaceutical, and material quality control applications However, several aspects require further refinement:
1. Limited Discussion on Sensitivity – The paper attributes the sensor’s low sensitivity (0.39%) to insufficient E-field concentration, but lacks further analysis or improvement strategies. A discussion on optimizing the antenna structure or measurement conditions would strengthen this section.
2. Equations (11) and (12) are crucial for permittivity calculation, yet their derivations are omitted. Providing additional explanations would improve transparency and credibility.
3. Table 3 compares methods but does not emphasize the unique advantages of the proposed sensor, such as cost-effectiveness or usability improvements
4. While the paper mentions potential applications, a more in-depth discussion on real-world deployment and industrial feasibility would add value.

Thank you for your contribution.

Yours sincerely

Penina Xie

On behalf of
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Dear

Associate Editor of PIERS Journal February 18, 2025

SUBMISSION OF REVISED MANUSCRIPT

Dear Professor,

Thank you for giving me the opportunity to submit a revised draft of manuscript *Close Quarters Permittivity Detection Based on Tagging Antenna Sensor for Solid Material Characterization* (Manuscript ID: 25010701).

We appreciate the time and effort that you and the reviewers have dedicated to providing your valuable feedback on my manuscript to be published as a research paper in the PIERS Journal.

We are grateful to the reviewers for their insightful comments on my paper. We have been able to incorporate changes to reflect most of the suggestions provided by the reviewers. We have highlighted *(red marker)* the changes within the manuscript.

We look forward to receiving your communication.

Yours sincerely,

Syah Alam*

Please address all correspondence to:

Syah Alam

Department of Electrical Engineering, Universitas Trisakti

*Corresponding author e-mail: syah.alam@trisakti.ac.id

Reviewer 1's Comments:

This study introduces a novel antenna sensor for permittivity detection of solid materials, leveraging resonance frequency shifts to determine permittivity through polynomial curve fitting. The proposed sensor achieves a high accuracy of 96% (Table 2) but exhibits limited sensitivity due to suboptimal E-field concentration. Validation against probe sensors demonstrates its potential for biomedical, pharmaceutical, and material quality control applications However, several aspects require further refinement:

Comment#1

The quality of the figures presented in the article should be improved to make them easily readable.

Response:

Thank you for the constructive comments from the reviewer. We agree with the reviewer comment. Therefore, we have improved all the figure resolution in revised paper (supplementary files)

Comment#2

Normally, FR-4 substrate has dielectric losses that are not negligible at high frequencies, which degrades the performance of the sensor antenna. Why was this material chosen rather than a low-loss substrate?

Response:

Thank you for the constructive comments from the reviewer. We agree with the reviewer's comment that FR-4 has high loss and can reduce the performance of the antenna. However, FR-4 has the advantages of low cost and compact dimensions. It should be noted that the focus of this work is to produce a microwave sensor that can detect the permittivity of solid materials using an interrogator antenna so that its performance is more prioritized as a permittivity sensor with a frequency shift-based approach. In addition, several previous works have also proposed FR-4 as a microwave sensor [23],[24]. Therefore, we use FR-4 as a microwave sensor in this work.

Reference:

[23] S. Alam, Z. Zakaria, I. Surjati, N. A. Shairi, M. Alaydrus, and T. Firmansyah, "Dual-Band Independent Permittivity Sensor Using Single-Port with a Pair of U-Shaped Structures for Solid Material Detection," *IEEE Sens. J.*, vol. 22, no. 16, pp. 16111–16119, 2022, doi: 10.1109/JSEN.2022.3191345.

[24] S. Alam *et al.*, "High Stability Single-Port Dual Band Microwave Sensor Based on Interdigital Capacitor Structure with Asymmetry Branch Feedline," *IEEE Access*, vol. 13, no. January, 2025, doi: 10.1109/ACCESS.2025.3538042.

Comment#3

Could the technique presented in this paper be used for high permittivity detection?

Response:

Thank you for the constructive comments from the reviewer. In this work, the detected material is focused on permittivity detection of low permittivity solid materials. We appreciate the feedback from reviewers to observe the performance of the proposed sensor for high permittivity detection. Therefore, high permittivity detection will be considered and presented in future work.

Comment#4

Could the technique presented in this paper be used for permittivity detection of materials with considerable dielectric losses?

Response:

Thank you for the constructive comments from the reviewer. The proposed sensor also can be used to detect dielectric losses based on changes of transmission coefficients (S_{21}). Therefore, we proposed simulation result of proposed sensor to detect dielectric losses in **Fig. 1**.

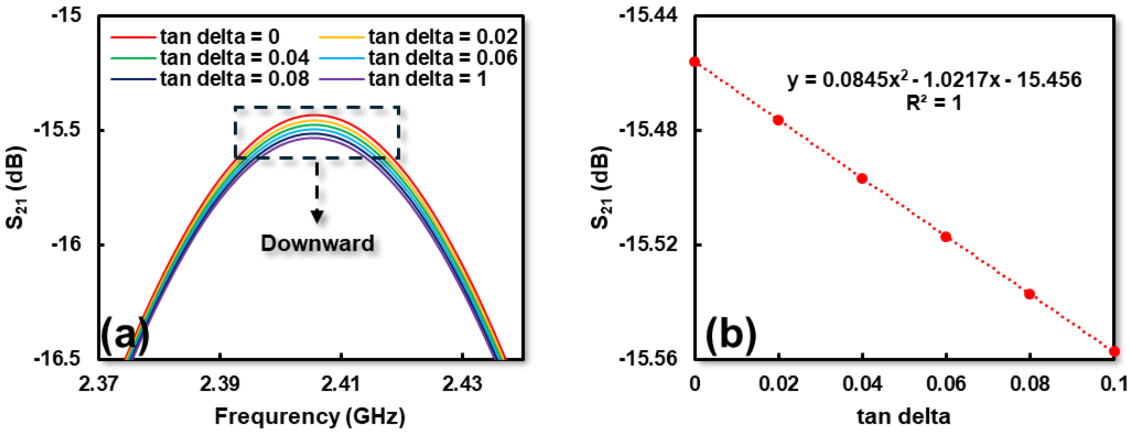

Fig.1 Simulation detection of tan delta with range of 0 – 0.1 using proposed sensor; (a) correlation resonance frequency with tan delta, (b) correlation between S_{21} and tan delta

Furthermore, the proposed sensor can also detect the change in dielectric losses of the sample based on the change in reflection coefficient (S_{21}) shown in **Fig. 1(a)**. The transmission coefficient of the proposed sensor moves to low along with the increase in dielectric loss of the sample in the range of 0 - 0.1. Based on the simulation results, the transmission coefficient shifts from -15.45 dB to -15.55 dB for the tan delta range of 0 - 0.1 as shown in Figure 1(b). This finding indicates that the change in tan delta of the sample greatly affects the transmission coefficient of the proposed sensor.

Action:

C. Simulation of tan delta detection using proposed sensor

*Furthermore, the proposed sensor can also detect the change in dielectric losses of the sample based on the change in reflection coefficient (S_{21}) shown in **Figure 5(a).** The transmission coefficient of the proposed sensor moves to low along with the increase in dielectric loss of the sample in the range of 0 - 0.1. Based on the simulation results, the transmission coefficient shifts from -15.45 dB to -15.55 dB for the tan delta range of 0 - 0.1 as shown in **Figure 5(b)**. This finding indicates that the change in tan delta of the sample greatly affects the transmission coefficient of the proposed sensor.*

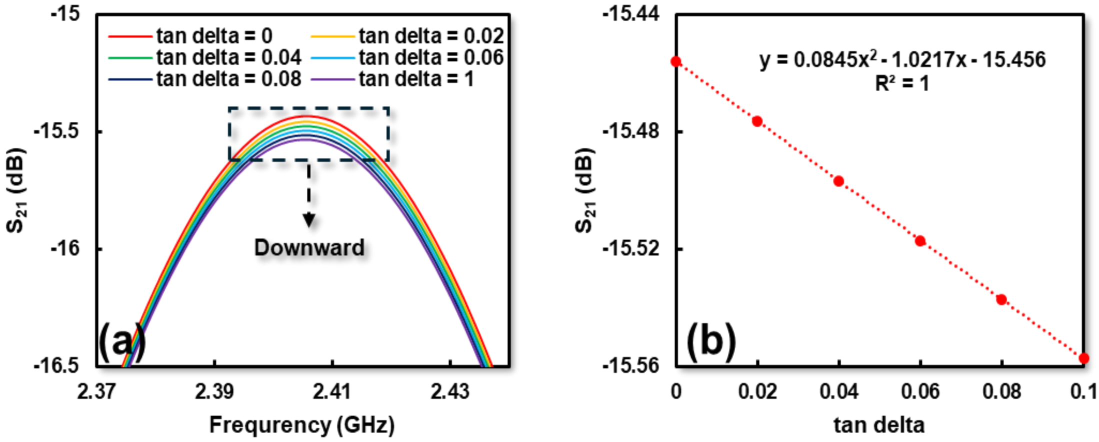

Figure 5. Simulation detection of tan delta with range of 0 – 0.1 using proposed sensor; (a) correlation resonance frequency with tan delta, (b) correlation between S_{21} and tan delta

Reviewer 2's comments:

The paper presents an innovative tagging antenna sensor for permittivity detection, demonstrating high accuracy (96%) and real-time measurement capability. The proposed design is well-structured, validated with simulations and experiments, and compared with existing works to highlight its advantages. However, certain comments that author can address to improve the quality of paper are as follows:

Comment #1:

The concept of tagging detection at a close distance is interesting but not fully explained in terms of practical applications.

Response:

Thank you for the constructive comments from the reviewer. We have explained in detail of practical application of proposed sensor in revised paper. In this paper, the sensor antenna is designed to operate at a resonant frequency of 2.4 GHz using an FR-4 substrate with a permittivity of 4.3, a thickness of 1.6 mm and a tan loss of 0.0265. Validation and verification of the proposed sensor is carried out using a Vector Network Analyzer (VNA) which is connected directly to the antenna using a coaxial cable and a computer using a USB cable. The sample used is solid which has certain dimensions with length, width and thickness represented by *a, b* and *h*. The sample is placed in the sensing area of the sensor antenna which is connected with port 1 of the VNA as the transmitter (T_x). Next, permittivity detection of the sample is proposed using an interrogator antenna connected to port 2 of the VNA as a receiver (Rx). The distance of T_x and R_x is determined based on the Fresnel region of the proposed antenna which is represented by d = $2D^2/\lambda$. The scenario of close quarter detection using the proposed sensor antenna is shown in **Figure 1**.

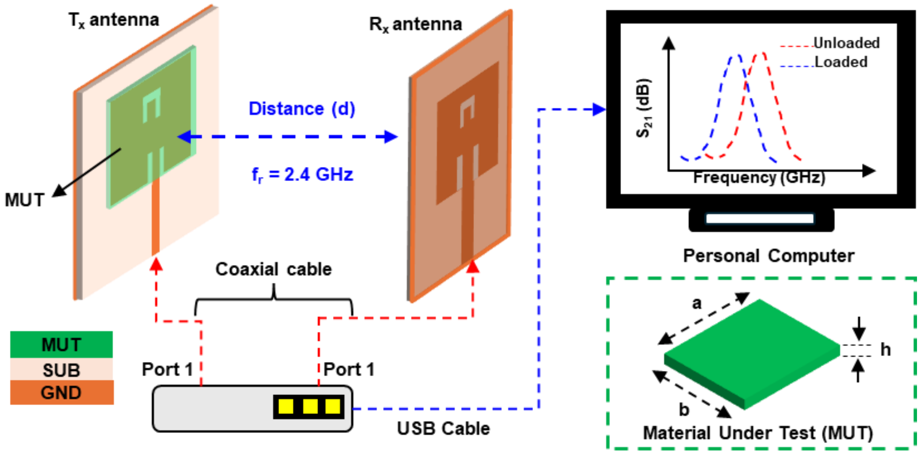

Figure 1. Proposed scenario for permittivity detection based on tagging antenna sensor

Permittivity detection is observed based on the frequency shift and response of the transmission coefficient parameter (S_{21}) of the interrogator antenna. Based on perturbation theory, the frequency of the resonator shifts lower in line with increasing permittivity of the sample placed in the sensing area of the antenna sensor.

The sensing area is determined based on the concentration of the electric field from the resonator which is represented by the E-field. Furthermore, the sample placed on the sensor antenna which functions as T_x will cause a frequency shift of the transmission coefficient on the interrogator antenna which functions as R_x. The correlation between frequency shift and permittivity change can be used to determine the permittivity of the sample using curve fitting based on polynomial equations.

Action:

II. Scenario for close-quarters permittivity detection based on tagging antenna sensor for solid materials

*In this paper, the sensor antenna is designed to operate at a resonant frequency of 2.4 GHz using an FR-4 substrate with a permittivity of 4.3, a thickness of 1.6 mm and a tan loss of 0.0265[12]. Validation and verification of the proposed sensor is carried out using a Vector Network Analyzer (VNA) which is connected directly to the antenna using a coaxial cable and a computer using a USB cable. The sample used is solid which has certain dimensions with length, width and thickness represented by a, b and h. The sample is placed in the sensing area of the sensor antenna which is connected with port 1 of the VNA as the transmitter (T_x). Next, permittivity detection of the sample is proposed using an interrogator antenna connected to port 2 of the VNA as a receiver (Rx). The distance of T_x and R_x is determined based on the Fresnel region of the proposed antenna which is represented by $d = 2D^2/\lambda$. The scenario of close quarter detection using the proposed sensor antenna is shown in **Figure 1**.*

Permittivity detection is observed based on the frequency shift and response of the transmission coefficient parameter (S_{21}) of the interrogator antenna. Based on perturbation theory, the frequency of the resonator shifts lower in line with increasing permittivity of the sample placed in the sensing area of the antenna sensor.

The sensing area is determined based on the concentration of the electric field from the resonator which is represented by the E-field. Furthermore, the sample placed on the sensor antenna which functions as T_x will cause a frequency shift of the transmission coefficient on the interrogator antenna which functions as R_x. The correlation between frequency shift and permittivity change can be used to determine the permittivity of the sample using curve fitting based on polynomial equations.

Comment #2:

How does this method compare with RFID-based permittivity sensors?

Response:

Thank you for the constructive comments from the reviewer. RF ID based permittivity sensor has the capability to detect permittivity of samples using horn antenna as interrogator. Generally, detection is determined based on RSSI parameter of designed sensor which is connected with RFID reader to capture interaction between sensor and sample. However, the configuration of complex measurement equipment becomes limitation. In addition, detection result must be processed using RFID reader which has potential to produce high error rate. In this paper, we proposed permittivity detection of solid material with simple measurement setup compared to RFID based method. This work proposes an antenna sensor for permittivity detection of samples based on a close quarter approach. A microwave sensor is proposed based on a resonator with a single port operating at a frequency of 2.4 GHz with reflection coefficient (S_{11}) ≤ -10 dB. Solid material samples are placed in the sensing area of the antenna sensor which is determined based on the electric field concentration. Furthermore, the interrogator antenna is proposed to detect permittivity with a certain distance (d) based on the frequency shift of the transmission coefficient parameters (S_{21}) of the antenna sensor. Validation and verification of the proposed sensor is carried out using a Vector Network Analyzer (VNA) which is connected directly to the antenna using a coaxial cable and a computer using a USB cable. The sample used is solid which has certain dimensions with length, width and thickness represented by *a, b* and *h*. The sample is placed in the sensing area of the sensor antenna which is connected with port 1 of the VNA as the transmitter (T_x). Next, permittivity detection of the sample is proposed using an interrogator antenna connected to port 2 of the VNA as a receiver (Rx). The distance of T_x and R_x is determined based on the Fresnel region of the proposed antenna which is represented by $d = 2D^2/\lambda$. The scenario of close quarter detection using the proposed sensor antenna is shown in **Figure 1**.

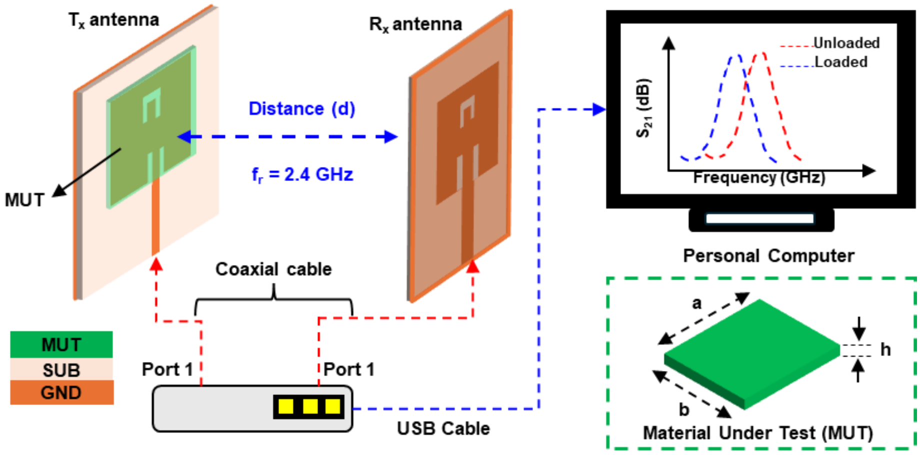

Figure 1. Proposed scenario for permittivity detection based on tagging antenna sensor

Permittivity detection is observed based on the frequency shift and response of the transmission coefficient parameter (S_{21}) of the interrogator antenna. Based on perturbation theory, the frequency of the resonator shifts lower in line with increasing permittivity of the sample placed in the sensing area of the antenna sensor.

The sensing area is determined based on the concentration of the electric field from the resonator which is represented by the E-field. Furthermore, the sample placed on the sensor antenna which functions as T_x will cause a frequency shift of the transmission coefficient on the interrogator antenna which functions as R_x. The correlation between frequency shift and permittivity change can be used to determine the permittivity of the sample using curve fitting based on polynomial equations.

Action:

I. Introduction

Material characterization is important to observe the performance and interaction of materials under certain conditions [1]. One of the parameters to determine material characterization is permittivity. Permittivity shows the ability of a material to store electrical energy that will interact with an electric field [2],[3]. The interaction between the electric field and the material can be observed based on perturbation theory where the energy stored in the material will perturb the electric field so that the resonance frequency will shift to a low frequency in line with an increase in the permittivity of the sample[4],[5].

Generally, the permittivity of samples is detected using commercial probe sensors, but they have limitations including complex structure, bulk and low accuracy [6],[7]. Microwave sensors are one device that can be recommended for detecting the permittivity of samples[8][9]. The advantages of microwave sensors include compact dimensions, high accuracy and high sensitivity[10],[11]. Previous work proposed permittivity detection of solid samples using microwave sensors using Split Ring Resonator (SRR)[12], Dual Split Ring Resonator (D-SRR) [13], Complementary Split Ring Resonator (CSRR) [14], T-resonator[15] and interdigital structure (IDC) [16]. However, detection is currently proposed to be performed directly using a resonator, which means it does not allow for reading detection with certain distance. Apart from that, the sensor proposed in previous work uses a resonator with two ports so it cannot function as an antenna for transmitting electromagnetic ***waves. Moreover, tagging detection can also be proposed using RFID based approaches. RF ID based permittivity sensor has the capability to detect permittivity of samples using horn antenna as interrogator. Generally, detection is determined based on RSSI parameter of designed sensor which is connected with RFID reader to capture interaction between sensor and sample[17]–[19]. However, the configuration of complex measurement equipment becomes limitation. In addition, detection result must be processed using RFID reader which has***

potential to produce high error rate. *Therefore, microwave sensors that have detection capabilities at a certain distance are needed to support real-time and flexible measurements.*

This work proposes an antenna sensor for permittivity detection of samples based on a close quarter approach. A microwave sensor is proposed based on a resonator with a single port operating at a frequency of 2.4 GHz with reflection coefficient (S_{11}) ≤ -10 dB. Solid material samples are placed in the sensing area of the antenna sensor which is determined based on the electric field concentration. Furthermore, the interrogator antenna is proposed to detect permittivity with a certain distance (d) based on the frequency shift of the transmission coefficient parameters (S_{21}) of the antenna sensor.

The main contribution of this work is producing an antenna sensor that has the capability for tagging detection using a close quarter approach based on frequency shift for solid material characterization. Finally, this research can be recommended for permittivity detection in solid materials in real time for several applications including biomedical, pharmaceutical and material quality control.

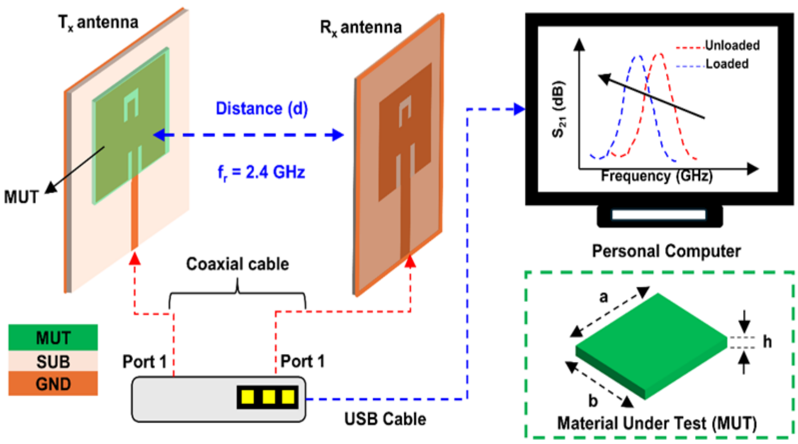

Figure 1. Proposed scenario for permittivity detection based on tagging antenna sensor

Reference:

[1] R. A. Alahnomi *et al.*, "Review of Recent Microwave Planar Resonator-Based Sensors :," *Sens. Rev.*, vol. 2267, no. 21, pp. 1–38, 2021.

[2] J. Yeo and J. I. Lee, "High-sensitivity microwave sensor based on an interdigital-capacitor-shaped defected ground structure for permittivity characterization," *Sensors (Switzerland)*, vol. 19, no. 3, 2019, doi: 10.3390/s19030498.

[3] S. Lim, C. Y. Kim, and S. Hong, "Simultaneous Measurement of Thickness and Permittivity by Means of the Resonant Frequency Fitting of a Microstrip Line Ring Resonator," *IEEE Microw. Wirel. Components Lett.*, vol. 28, no. 6, pp. 539–541, 2018, doi: 10.1109/LMWC.2018.2833202.

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[11] S. Alam *et al.*, "UHF-Band Solid Sensor Based on Tweaking Electric Field Coupled Resonator for Material Characterization," *Prog. Electromagn. Res. M*, vol. 126, no. February, pp. 11–18, 2024, doi: 10.2528/PIERM24020201.

[12] A. Armghan, T. M. Alanazi, A. Altaf, and T. Haq, "Characterization of Dielectric Substrates Using Dual Band Microwave Sensor," *IEEE Access*, vol. 9, pp. 62779–62787, 2021, doi: 10.1109/ACCESS.2021.3075246.

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Resonator Sensor," *Appl. Comput. Electromagn. Soc. J.*, vol. 37, no. 2, pp. 222–228, 2022, doi: 10.13052/2022.ACES.J.370211.
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Comment #3:

Would there be interference if multiple tagged objects are placed within the sensing range?

Response:

Thank you for the constructive comments from the reviewer. We agree with the reviewer's comment that multiple tagged objects on the sensor can cause interference. We agree with the reviewer's comment that multiple tagged objects on the sensor can cause interference. Therefore, the dimensions of the detected sample are adjusted to the width of the sensing area to prevent interference from multiple objects. In this paper, four types of solid materials are proposed as samples as follows: polystyrene, polypropylene, PVC and rubber. The permittivity of the sample was validated using a Keysight N1501A dielectric probe kit which was used as a reference to determine the permittivity of the sample using the proposed antenna sensor. The dimensions of the sample are adjusted to the location of the sensing area where the length, width and thickness are 36 mm x 28 mm x 1 mm respectively. Furthermore, to ensure accurate sample placement, plastic clamps were used to attach the sample to the surface of the antenna sensor. A comparison of simulation and measurement results from the antenna sensor for S_{11} and S_{21} is shown in **Figure 5(b)**.

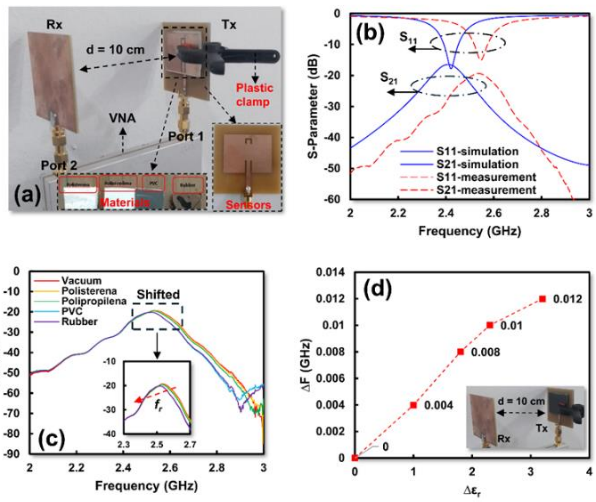

Figure 5. Measurement of proposed sensor; (a) setup for detection using tagging antenna sensor, (b) simulation and measurement result, (c) response of frequency with permittivity changes, (d) ΔF of proposed sensor.

Action:

A. Measurement and verification

Measurements and verification of the proposed antenna sensor were carried out in the laboratory using a Vector Network Analyzer (VNA) with a frequency range of 2 - 2.8 GHz with a frequency step size of 0.001 GHz and an ambient temperature of 25^0 C. Measurement setup for permittivity detection with a tagging antenna sensor with a distance of d = 10 cm where the sample is placed on the T_x antenna which is connected to port 1 while for the R_x antenna it is connected to port 2 as shown in ***Figure 5(a)***.

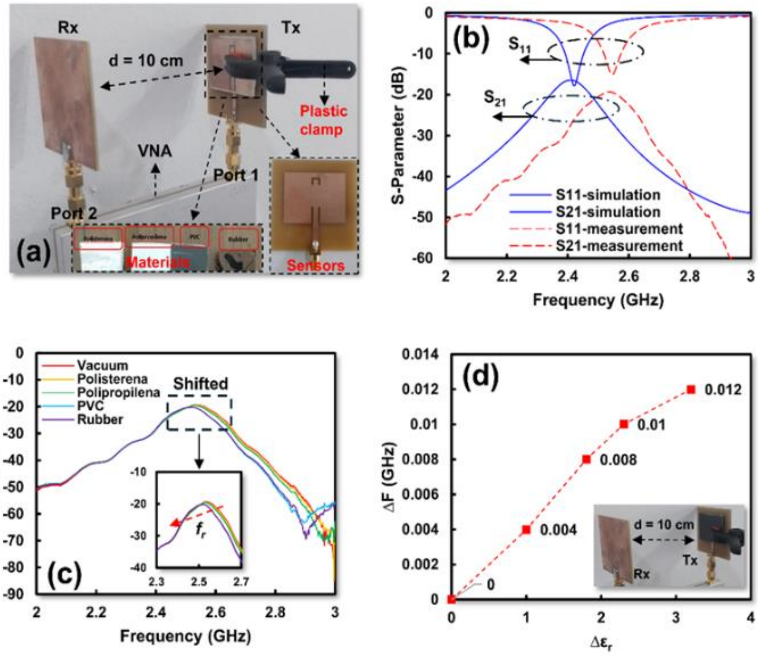

Figure 5. Measurement of proposed sensor; (a) setup for detection using tagging antenna sensor, (b) simulation and measurement result, (c) response of frequency with permittivity changes, (d) ΔF of proposed sensor.

In this experiment, four types of solid materials are proposed as samples as follows: polystyrene, polypropylene, PVC and rubber. The permittivity of the sample was validated using a Keysight N1501A dielectric probe kit which was used as a reference to determine the permittivity of the sample using the proposed antenna sensor. ***The dimensions of the sample are adjusted to the location of the sensing area where the length, width and thickness are 36 mm x 28 mm x 1 mm respectively***.

Comment #4:

The paper states that the design is based on a resonator operating at 2.4 GHz, but experimental results show it at 2.53 GHz.

Response:

Thank you for the constructive comments from the reviewer. We have explained in the revised paper that the resonance frequency of proposed sensor has a slight difference between simulation and measurement. Based on the measurement results, the sensor antenna experienced a frequency shift from 2.4 GHz to 2.53 GHz or a shift of 5.4 %. This result is due to the uncertainty of the fabrication process and the permittivity range of the FR4 substrate where ε_r = 4.3 - 4.6.

Action:

Based on the measurement results, the sensor antenna experienced a frequency shift from 2.4 GHz to 2.53 GHz or a shift of 5.4 %. This result is due to the uncertainty of the fabrication process and the permittivity range of the FR4 substrate where ε_r = 4.3 - 4.6. *The correlation between the resonance frequency of the antenna sensor and changes in the permittivity of the sample is shown in* ***Figure 5(c)*** *where the resonance frequency shifts to a low frequency in line with the increase in the permittivity of the sample. The resonant frequency of the antenna sensor shifts from 2.534 GHz to 2.532 GHz for the four recommended samples with different permittivity. In this experiment, the reference frequency used was the unloaded condition (vacuum). Next, the range of frequency shift of the antenna sensor represented by ΔF is determined based on the following equation:*

$$\Delta F = f_{unloaded} - f_{loaded}\ (GHz) \qquad (10)$$

Comment #5:

The authors should explain the impact of this frequency shift on real-world applications.

Response:

Thank you for the constructive comments from the reviewer. We agree that the resonant frequency of the sensor has a slight shift from 2.4 GHz to 2.53 GHz. Therefore, the proposed sensor can be used and integrated with WiMAX operating at 2.3 GHz, 2.5 GHz, and 3.5 GHz.

Comment #6:

The study defines the Tx-Rx separation using the Fresnel region formula, but practical justification is missing.

Response:

Thank you for the constructive comments from the reviewer. In this paper, the sensor antenna is designed to operate at a resonant frequency of 2.53 GHz using an FR-4 substrate with a permittivity of 4.3, a thickness of 1.6 mm and a tan loss of 0.0265. To determine specific distance value for far field and near field region we refer to the formula for Fresnel region [11].

- Distance for near field is $\leq \frac{2D^2}{\lambda}$
- Distance for far field is $\geq \frac{2D^2}{\lambda}$

Where D is dimension of the antenna and λ represented wavelength of the antenna based on the resonance frequency. Furthermore, the proposed resonance frequencies are f_{r1} = 2.53 GHz while the antenna diameter (D) is 50 mm. By using the formula from Fresnel region, the maximum distance of far field is ≥ 4.23 cm. In this work, we use a distance of d = 10 cm for far field region, and it meets the criteria for far field distances.

Action:

II. Scenario for close-quarters permittivity detection based on tagging antenna sensor for solid materials

In this paper, the sensor antenna is designed to operate at a resonant frequency of 2.4 GHz using an FR-4 substrate with a permittivity of 4.3, a thickness of 1.6 mm and a tan loss of 0.0265[12]. Validation and verification of the proposed sensor is carried out using a Vector Network Analyzer (VNA) which is connected directly to the antenna using a coaxial cable and a computer using a USB cable. The sample used is solid which has certain dimensions with length, width and thickness represented by a, b and h. The sample is placed in the sensing area of the sensor antenna which is connected with port 1 of the VNA as the transmitter (T_x). Next, permittivity detection of the sample is proposed using an interrogator antenna connected to port 2 of the VNA as a receiver (Rx). The distance of T_x and R_x is determined based on the Fresnel region of the proposed antenna which is represented by $d = 2D^2/\lambda$. The scenario of close quarter detection using the proposed sensor antenna is shown in ***Figure 1****.*

Permittivity detection is observed based on the frequency shift and response of the transmission coefficient parameter (S_{21}) of the interrogator antenna. Based on perturbation theory, the frequency of the resonator shifts lower in line with increasing permittivity of the sample placed in the sensing area of the antenna sensor.

The sensing area is determined based on the concentration of the electric field from the resonator which is represented by the E-field. Furthermore, the sample placed on the sensor antenna which functions as T_x will cause a frequency shift of the transmission coefficient on the interrogator antenna which functions as R_x. The correlation between frequency shift and permittivity change can be used to determine the permittivity of the sample using curve fitting based on polynomial equations.

Comment #6:

Would the performance remain stable if the distance varies slightly due to real-world deployment constraints?

Response:

Thank you for the constructive comments from the reviewer. We agree with the reviewer comment that the performance of proposed sensor needs to be observed with several distances. Therefore, we proposed simulation result of detection using proposed sensor with distance of d = 5 cm – 15 cm. Based on the simulation results, the sensor can detect the permittivity of the sample for the distance range d = 5 cm - 15 cm as shown in Figure 1 (a), Figure 1 (b) and Figure 1 (c). Furthermore, the correlation of the resonance frequency and permittivity is shown in Figure 1 (d) where the performance of the sensor is stable enough to detect the permittivity of the sample for the range d = 5 cm - 15 cm. The simulation results show that the resonance frequency shifts from 2.408 GHz to 2.401 GHz for d = 5 cm while for d = 10 cm it shifts from 2.406 GHz to 2.398 GHz and for d = 15 cm it shifts from 2.406 GHz to 2.397 GHz. Other findings show that the distance between the sensor and the interrogator antenna greatly affects the transmission coefficient (S_{21}) of the antenna where a long distance causes the transmission coefficient of the sensor to shift to low. The simulation results show that the S_{21} of the proposed sensor shifts from -9.45 dB to -15.41 dB and -20.99 dB for the distance range d = 5 cm - 10 cm. This finding indicates that the distance between the sensor and the interrogator antenna should be determined based on the fresnel region. Therefore, in this paper, the distance between the sensor and the antenna is determined based on the fresnel region which is represented by $d = 2D^2/\lambda$.

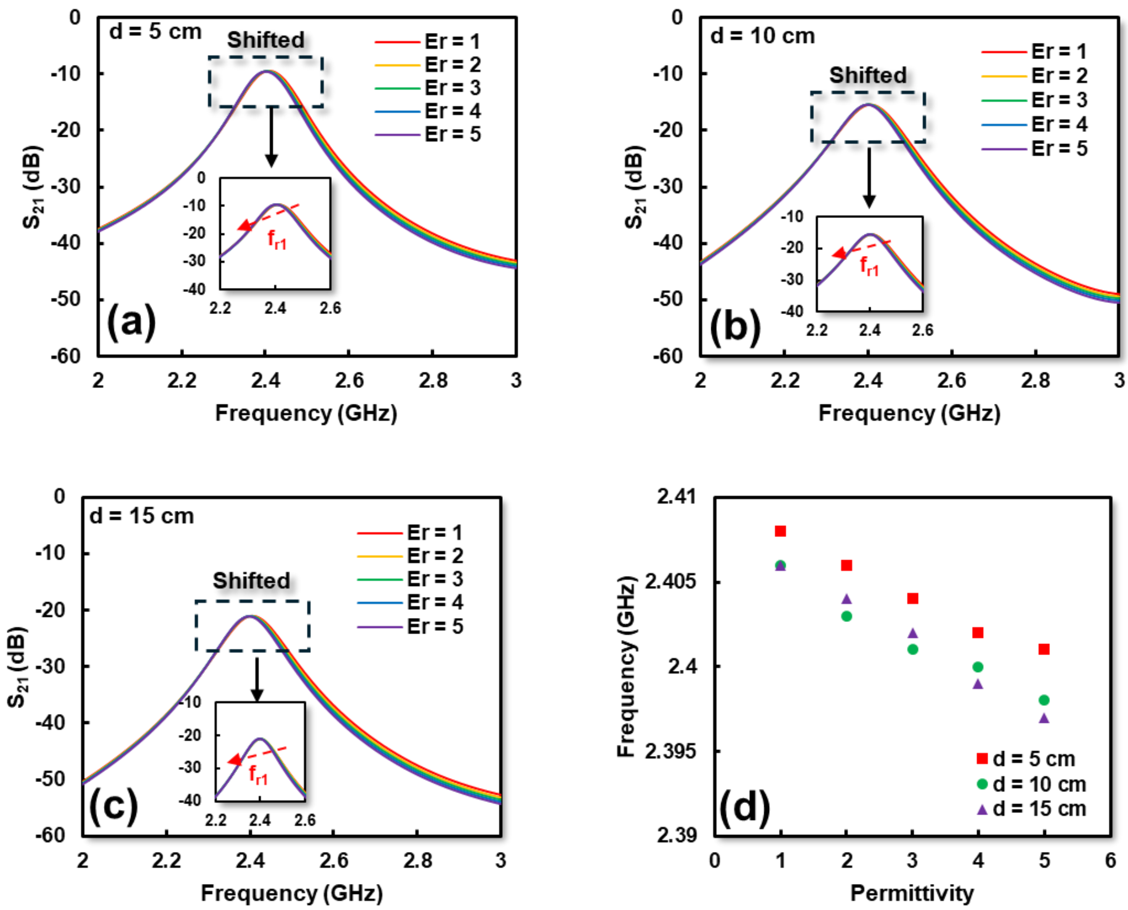

Figure. 2 Simulation detection of tan delta with range of d = 5 cm – 15 cm using proposed sensor; (a) d = 5 cm, (b) d = 10 cm, (c) d = 15 cm, (d) correlation between distance with resonance frequency and permittivity of samples, (e) correlation between distance and S_{21}

Action:

D. Simulation of permittivity detection using antenna sensor with d = 5 cm – 10 cm

*Furthermore, simulation with EM simulation is proposed to observe the performance of the proposed sensor against the distance between the sensor and the interrogator antenna represented by d for the range of 5 cm - 15 cm as shown in **Figure 6**. Based on the simulation results, the sensor can detect the permittivity of the sample for the distance range d = 5 cm - 15 cm as shown in **Figure 6 (a)**, **Figure 6 (b)** and **Figure 6 (c)**. Furthermore, the correlation of the resonance frequency and permittivity is shown in **Figure 6 (d)** where the performance of the sensor is stable enough to detect the permittivity of the sample for the range d = 5 cm - 10 cm. The simulation results show that the resonance frequency shifts from 2.408 GHz to 2.401 GHz for d = 5 cm while for d = 10 cm it shifts from 2.406 GHz to 2.398 GHz and for d = 15 cm it shifts from 2.406 GHz to 2.397 GHz.*

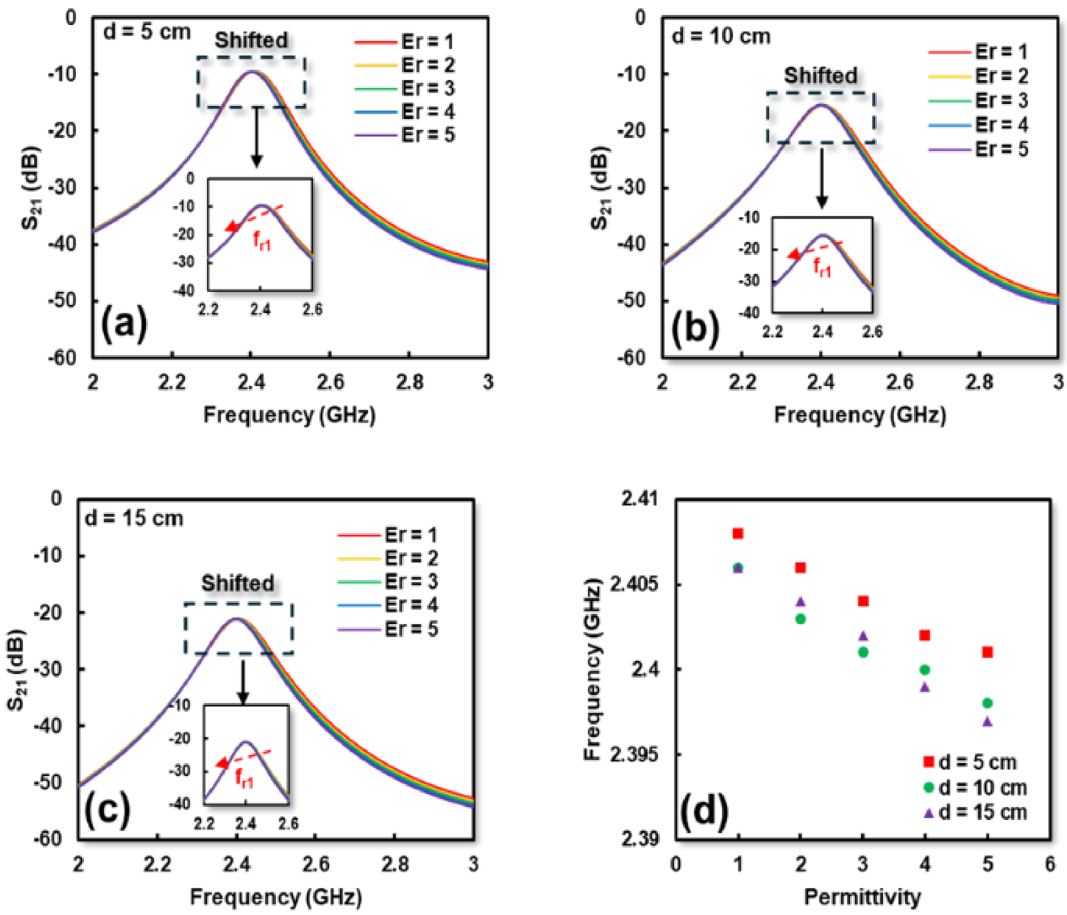

Figure 6. Simulation detection of tan delta with range of d = 5 cm – 15 cm using proposed sensor; (a) d = 5 cm, (b) d = 10 cm, (c) d = 15 cm, (d) correlation between distance with resonance frequency and permittivity of samples, (e) correlation between distance and S_{21}

Other findings show that the distance between the sensor and the interrogator antenna greatly affects the transmission coefficient (S_{21}) of the antenna where a long distance causes the transmission coefficient of the sensor to shift to low. The simulation results show that the S21 of the proposed sensor shifts from -9.45 dB to -15.41 dB and -20.99 dB for the distance range d = 5 cm - 10 cm. This finding indicates that the distance between the sensor and the interrogator antenna should be determined based on the fresnel region. Therefore, in this paper, the distance between the sensor and the antenna is determined based on the Fresnel region which is represented by $d = 2D^2/\lambda$.

Comment #7:

Compared to prior works (which reported sensitivity up to 14%), the proposed sensor's sensitivity is significantly lower.

Response:

Thank you for the constructive comments from the reviewer. We agree with the reviewer comment that the proposed sensor has a low sensitivity due to the low concentration of the electric field. Therefore, antenna sensors that produce higher electric field concentrations are highly recommended for future work. Previous work [13][14][15][16] proposed microwave sensors for permittivity detection of solid materials using Dual SRR, Nested SRR, T-ring resonator and interdigital structure. However, the proposed work is not capable of tagging detection over a certain distance. Table 3 shows that the main contribution of this work is producing an antenna sensor that has the capability for tagging detection using a close quarter approach based on frequency shift for solid material characterization. Moreover, the proposed antenna sensor has a high accuracy of 96% for the permittivity range 1 - 4.13.

Reference:

[13] A. J. A. Al-Gburi, Z. Zakaria, I. M. Ibrahim, R. S. Aswir, and S. Alam, “Solid Characterization Utilizing Planar Microwave Resonator Sensor,” *Appl. Comput. Electromagn. Soc. J.*, vol. 37, no. 2, pp. 222–228, 2022, doi: 10.13052/2022.ACES.J.370211.

[14] N. A. Rahman *et al.*, “High quality factor using nested complementary split ring resonator for dielectric properties of solids sample,” *Appl. Comput. Electromagn. Soc. J.*, vol. 35, no. 10, pp. 1222–1227, 2020, doi: 10.47037/2020.ACES.J.351016.

[15] R. A. Alahnomi, Z. Zakaria, Z. M. Yussof, T. Sutikno, A. A. Mohd Bahar, and A. Alhegazi, “Determination of solid material permittivity using T-ring resonator for food industry,” *Telkomnika (Telecommunication Comput. Electron. Control.*, vol. 17, no. 1, pp. 489–496, 2019, doi: 10.12928/TELKOMNIKA.v17i1.11636.

[16] S. Kiani, P. Rezaei, M. Navaei, and M. S. Abrishamian, “Microwave Sensor for Detection of Solid Material Permittivity in Single/Multilayer Samples With High Quality Factor,” *IEEE Sens. J.*, vol. 18, no. 24, pp. 9971–9977, 2018, doi: 10.1109/JSEN.2018.2873544.

Comment #8:

The authors acknowledge this limitation but do not provide suggestions on how to improve it.

Response:

Thank you for the constructive comments from the reviewer. We have provided suggestions to improve the sensitivity of proposed sensor with combining single port resonator with Interdigital Structure (IDC) [24] and Artificial Magnetic Coupled resonator [25] as sensing area with high concentrations of electric field.

Action:

Furthermore, validation of this work was carried out by comparing the performance of the proposed antenna sensor with the microwave sensor proposed in previous work as shown in Table 3. The performance of the sensors compared included resonance frequency, sample type, permittivity range, accuracy, sensitivity and capability for tagging detection with a close quarter approach.

Previous work [13][14][15][16] proposed microwave sensors for permittivity detection of solid materials using Dual SRR, Nested SRR, T-ring resonator and interdigital structure. However, the proposed work is not capable of tagging detection over a certain distance. Table 3 shows that the main contribution of this work is producing an antenna sensor that has the capability for tagging detection using a close quarter approach based on frequency shift for solid material characterization. Moreover, the proposed antenna sensor has a high accuracy of 96% for the permittivity range 1 - 4.13. However, the sensitivity of the antenna sensor is still small because the E-field is not optimally concentrated. Therefore, increasing the sensitivity of the antenna sensor can be recommended as further work such as combining the structure of single port *resonator with interdigital capacitor (IDC) structures [24] or using artificial magnetic coupled (AMC) as sensing area with high concentrations of electric field [25].*

Reference:

[13] A. J. A. Al-Gburi, Z. Zakaria, I. M. Ibrahim, R. S. Aswir, and S. Alam, "Solid Characterization Utilizing Planar Microwave Resonator Sensor," *Appl. Comput. Electromagn. Soc. J.*, vol. 37, no. 2, pp. 222–228, 2022, doi: 10.13052/2022.ACES.J.370211.

[14] N. A. Rahman *et al.*, "High quality factor using nested complementary split ring resonator for dielectric properties of solids sample," *Appl. Comput. Electromagn. Soc. J.*, vol. 35, no. 10, pp. 1222–1227, 2020, doi: 10.47037/2020.ACES.J.351016.

[15] R. A. Alahnomi, Z. Zakaria, Z. M. Yussof, T. Sutikno, A. A. Mohd Bahar, and A. Alhegazi, "Determination of solid material permittivity using T-ring resonator for food industry," *Telkomnika (Telecommunication Comput. Electron. Control.*, vol. 17, no. 1, pp. 489–496, 2019, doi: 10.12928/TELKOMNIKA.v17i1.11636.

[16] S. Kiani, P. Rezaei, M. Navaei, and M. S. Abrishamian, "Microwave Sensor for Detection of Solid Material Permittivity in Single/Multilayer Samples With High Quality Factor," *IEEE Sens. J.*, vol. 18, no. 24, pp. 9971–9977, 2018, doi: 10.1109/JSEN.2018.2873544.

Reference for improving sensitivity of proposed sensor

[24] S. Alam *et al.*, "High Stability Single-Port Dual Band Microwave Sensor Based on Interdigital Capacitor Structure with Asymmetry Branch Feedline," *IEEE Access*, vol. 13, no. January, 2025, doi: 10.1109/ACCESS.2025.3538042.

[25] W. J. Wu and G. Wang, "A modified AMC-based antenna sensor for contactless measurement of complex permittivity," *Meas. J. Int. Meas. Confed.*, vol. 206, no. June 2022, p. 112261, 2023, doi: 10.1016/j.measurement.2022.112261.

Comment #9:

Can structural modifications (e.g., optimized slot configurations) enhance E-field concentration for better sensitivity?

Thank you for the constructive comments from the reviewer. We have provided suggestions to improve the sensitivity of proposed sensor with combining single port resonator with Interdigital Structure (IDC) [24] and Artificial Magnetic Coupled resonator [25] as sensing area with high concentrations of electric field.

Action:

Furthermore, validation of this work was carried out by comparing the performance of the proposed antenna sensor with the microwave sensor proposed in previous work as shown in Table 3. The performance of the sensors compared included resonance frequency, sample type, permittivity range, accuracy, sensitivity and capability for tagging detection with a close quarter approach.

Previous work [13][14][15][16] proposed microwave sensors for permittivity detection of solid materials using Dual SRR, Nested SRR, T-ring resonator and interdigital structure. However, the proposed work is not capable of tagging detection over a certain distance. Table 3 shows that the main contribution of this work is producing an antenna sensor that has the capability for tagging detection using a close quarter approach based on frequency shift for solid material characterization. Moreover, the proposed antenna sensor has a high accuracy of 96% for the permittivity range 1 - 4.13. However, the sensitivity of the antenna sensor is still small because the E-field is not optimally concentrated. Therefore, increasing the sensitivity of the antenna sensor can be recommended as further work such as combining the structure of single port resonator with interdigital capacitor (IDC) structures [24] or using artificial magnetic coupled (AMC) as sensing area with high concentrations of electric field [25].

Comment #10:

The shift in frequency is relatively small. Could external factors such as temperature and humidity variations affect this shift?

Response:

Thank you for the constructive comments from the reviewer. In this paper, the measurements and verification of the proposed antenna sensor were carried out in the laboratory using a Vector Network Analyzer (VNA) with a frequency range of 2 - 2.8 GHz with a frequency step size of 0.001 GHz and an ambient temperature of 25^0 C. We agree that temperature and humidity variations have an effect with the performance of the proposed sensor. Therefore, we must ensure that the measurement process must be carried out at room temperature around 25^0 C.

Comment #11:

Would noise in real-time environments impact measurement stability?

Thank you for the constructive comments from the reviewer. In this paper, the measurements and verification of the proposed antenna sensor were carried out in the laboratory using a Vector Network Analyzer (VNA) with a frequency range of 2 - 2.8 GHz with a frequency step size of 0.001 GHz and an ambient temperature of 25^0 C. In this paper, the proposed sensor and interrogator antenna have identical performance and resonance frequency. We agree that noise can affect the performance and interfere with the resonance frequency of the proposed sensor. In this paper, the proposed sensor and interrogator antenna have identical performance and resonance frequency. We agree that noise can affect the performance and interfere with the resonance frequency of the proposed sensor. Therefore, we ensure that in the measurement process there is no interference from other frequencies and the sensor is free from obstacles that can cause interference and decrease the performance of the proposed sensor.

Comment #12:

The deviation from the reference permittivity values is provided in Table 2, but there is no discussion on sources of error.

Response:

Thank you for the constructive comments from the reviewer. We agree with the reviewer comment that there is a deviation between the measurement results of permittivity detection using the proposed sensor and the commercial probe sensor. The errors from measurement process arise from multiple sources, including calibration inaccuracies, environmental factors, and sensor design limitations. To minimize these errors, advanced calibration techniques, shielding from environmental interference, and improved sensor designs incorporating robust signal processing methods are essential. Therefore, we have added this discussion in revised paper.

Action:

Table 2. Comparison measurements from antenna sensor and probe sensors

Samples	Permittivity		Error (%)	Accuracy (%)
	Probe sensor	Antenna sensor		
Vacuum	1.05	1.02	2.7	97.31
Polystyrene	1.84	2.02	8.9	91.12
Polypropylene	2.85	2.82	1.1	98.85
PVC	3.44	3.32	3.6	96.38
Rubber	4.08	4.12	0.9	99.09

Table 2 shows that the proposed antenna sensor has high accuracy for permittivity detection of the four solid materials with a range of 91% - 99%. Moreover, errors from measurement process arise from multiple sources, including calibration inaccuracies, environmental factors, and sensor design limitations. To minimize these errors, advanced calibration techniques, shielding from environmental interference, and improved sensor designs incorporating robust signal processing methods are essential.

Comment #13:

Factors such as fabrication imperfections, VNA calibration, and environmental noise should be discussed.

Response:

Thank you for the constructive comments from the reviewer. We agree with the reviewer comment that there is a deviation between the measurement results of permittivity detection using the proposed sensor and the commercial probe sensor. The errors from measurement process arise from multiple sources, including calibration inaccuracies, environmental factors, and sensor design limitations. To minimize these errors, advanced calibration techniques, shielding from environmental interference, and improved sensor designs incorporating robust signal processing methods are essential. Therefore, we have added this discussion in revised paper.

Action:

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PVC	3.44	3.32	3.6	96.38
Rubber	4.08	4.12	0.9	99.09

Table 2 shows that the proposed antenna sensor has high accuracy for permittivity detection of the four solid materials with a range of 91% - 99%. Moreover, errors from measurement process

arise from multiple sources, including calibration inaccuracies, environmental factors, and sensor design limitations. To minimize these errors, advanced calibration techniques, shielding from environmental interference, and improved sensor designs incorporating robust signal processing methods are essential.

Comment #14:

The study uses a Keysight N1501A dielectric probe kit as a reference. However, the accuracy comparison does not account for variations in probe-based measurements.

Response:

Thank you for the constructive comments from the reviewer. In this experiment, four types of solid materials are proposed as samples as follows: polystyrene, polypropylene, PVC and rubber. The permittivity of the sample was validated using a Keysight N1501A dielectric probe kit which was used as a reference to determine the permittivity of the sample using the proposed antenna sensor. The dimensions of the sample are adjusted to the location of the sensing area where the length, width and thickness is 36 mm x 28 mm x 1 mm respectively.

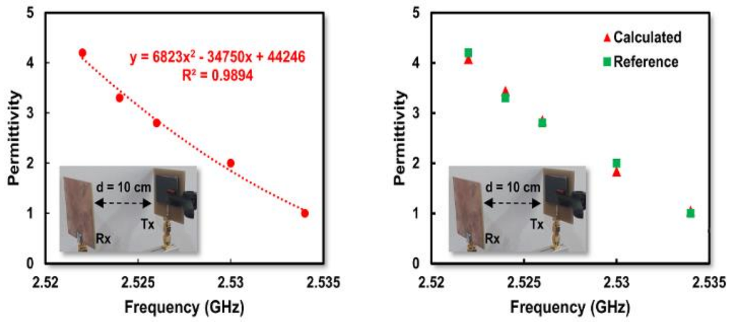

Figure 8. (a) Fitting curve for permittivity detection, (b) comparison permittivity from calculation and reference

Comment #15:

Are the probe sensor readings affected by sample thickness, surface roughness, or air gaps?

Response:

Thank you for the constructive comments from the reviewer. We agree with the reviewer comment that the probe sensor affected by sample thickness, surface roughness, or air gaps. In this paper, Keysight N1501A dielectric probe kit which was used as a reference to determine the permittivity of the sample using the proposed antenna sensor. The dimensions of the sample are adjusted to the location of the sensing area where the length, width and thickness is 36 mm x 28 mm x 1 mm respectively. Moreover, we ensure that the samples directly loaded in the probe sensor without air gap. In addition, we used same dimension and roughness samples both for detection using proposed sensor and Keysight N1501A dielectric probe kit.

Comment #16:

The legend and axis labels are unclear. It should explicitly mention what each curve represents.

Response:

Thank you for the constructive comments from the reviewer. We have corrected the legend axis label in the revised manuscript (supplementary files).

Comment #17:

The 'Close Quarter Approach' column lists only "Yes" or "No" without quantitative comparisons. A brief explanation of each study's limitations would improve readability.

Response:

Thank you for the constructive comments from the reviewer. We have explained quantitative comparisons between proposed sensor with previous work including ΔF, Sensitivity and Accuracy as shown in Table 3.

Table 3. Comparison proposed antenna sensor with existing works

Ref.	Method	f_r (GHz)	Permittivity range	Samples	Sensing parameter	Sensing performance			Tagging detection	Close quarter approach
						ΔF (GHz)	Acc. (%)	Sens. (%)		
[13]	Dual SRR	2.27	1 – 4.3	Solid	Freq. shift	0.29	85%	8.52	No	No
[14]	Nested CSRR	3.37	1 – 4.3	Solid	Freq. shift	0.47	87%	14.02	No	No
[15]	T-ring resonator	4.2	1 – 4.3	Solid	Freq. shift	0.18	95%	5.45	No	No
[16]	Interdigital structure	5.65	1 – 4.3	Solid	Freq. shift	0.17	98%	3.25	No	No
This work	Antenna with U -slot	2.53	1 – 4.13	Solid	Freq. shift	0.012	96%	0.39	Yes	Yes

Furthermore, validation of this work was carried out by comparing the performance of the proposed antenna sensor with the microwave sensor proposed in previous work as shown in **Table 3**. The performance of the sensors compared included resonance frequency, sample type, permittivity range, accuracy, sensitivity and capability for tagging detection with a close quarter approach.

Previous work [13][14][15][16] proposed microwave sensors for permittivity detection of solid materials using Dual SRR, Nested SRR, T-ring resonator and interdigital structure. However, the proposed work is not capable of tagging detection over a certain distance. **Table 3** shows that the main contribution of this work is producing an antenna sensor that has the capability for tagging detection using a close quarter approach based on frequency shift for solid material characterization. Moreover, the proposed antenna sensor has a high accuracy of 96% for the permittivity range 1 - 4.13. However, the sensitivity of the antenna sensor is still small because the E-field is not optimally concentrated. Therefore, increasing the sensitivity of the antenna sensor can be recommended as further work such as combining the structure of single port resonator with interdigital capacitor (IDC) structures [24] or using artificial magnetic coupled (AMC) as sensing area with high concentrations of electric field[25].

Comment #18:

Some equations (e.g., Equations 1–5) are introduced without proper in-text references. They should be cited appropriately within the explanations.

Response:

Thank you for the constructive comments from the reviewer. We have added citations for equations that we used in this paper. We also give clear explanation about the parameters in each formula

Action:

The dimensions of the sensor antenna are determined based on the resonant frequency and characteristics of the substrate used. The length and width of the antenna patch represented by W_p and L_p are determined based on the following equation[20]:

$$W_p = \frac{c}{2f_o\sqrt{\frac{(\varepsilon r+1)}{2}}} \tag{1}$$

$$L_p = L_{eff} - \Delta_L \tag{2}$$

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} \tag{3}$$

$$\varepsilon_{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}[1 + 12\frac{h}{W_p}]^{-\frac{1}{2}} \tag{4}$$

$$\Delta_L = 0.412\frac{(\varepsilon_{reff} + 0.3)\,(\frac{Wp}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)\,(\frac{Wp}{h} + 0.8)} \tag{5}$$

where W_p and L_p denote the patch's length and width, respectively, f_o stands for the resonance frequency, ε_r is the substrate's permittivity, ε_{eff} indicates the substrate's effective permittivity at a specific resonance frequency, h signifies the substrate's thickness; and ΔL accounts for the fringing field's edge effect on the patch.

Additionally, microstrip lines are suggested to regulate the antenna's impedance and reflection coefficient represented by W_z. The dimensions of the microstrip line are significantly affected by the input impedance and the chosen resonant frequency. In this study, the input impedance is set at 50 ohms. The dimensions of the microstrip line can be calculated using the following equation[21]:

$$W_z = \frac{2h}{\pi}\left\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}[\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}]\right\} \tag{6}$$

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_{eff}}} \tag{7}$$

In this context, W_z represents the width of the microstrip line, Z_0 denotes the antenna impedance, and B is the impedance constant. The antenna's impedance is set at 50 Ω, consistent with the impedance of the connector employed.

Comment #19:

Some sentences are awkwardly structured. For example:

"The sensing area is determined based on the concentration of the electric field from the resonator which is represented by the E-field." It would be clearer as: **"The sensing area is defined by the region with maximum electric field concentration, as indicated by the E-field distribution."**

Response:

Thank you for the constructive comments from the reviewer. We have corrected the sentences based on reviewer suggestions.

Action:

*In this paper, the sensor antenna is designed to operate at a resonant frequency of 2.4 GHz using an FR-4 substrate with a permittivity of 4.3, a thickness of 1.6 mm and a tan loss of 0.0265[12]. Validation and verification of the proposed sensor is carried out using a Vector Network Analyzer (VNA) which is connected directly to the antenna using a coaxial cable and a computer using a USB cable. The sample used is solid which has certain dimensions with length, width and thickness represented by a, b and h. The sample is placed in the sensing area of the sensor antenna which is connected with port 1 of the VNA as the transmitter (T_x). Next, permittivity detection of the sample is proposed using an interrogator antenna connected to port 2 of the VNA as a receiver (Rx). The distance of T_x and R_x is determined based on the Fresnel region of the proposed antenna which is represented by $d = 2D^2/\lambda$. The scenario of close quarter detection using the proposed sensor antenna is shown in **Figure 1**.*

Permittivity detection is observed based on the frequency shift and response of the transmission coefficient parameter (S_{21}) of the interrogator antenna. Based on perturbation theory, the frequency of the resonator shifts lower in line with increasing permittivity of the sample placed in the sensing area of the antenna sensor.

The sensing area is defined by the region with maximum electric field concentration, as indicated by the E-field distribution. Furthermore, the sample placed on the sensor antenna which functions as T_x will cause a frequency shift of the transmission coefficient on the interrogator antenna which functions as R_x. The correlation between frequency shift and permittivity change can be used to determine the permittivity of the sample using curve fitting based on polynomial equations.

Comment #20:

The abstract is informative but should briefly mention the limitations (e.g., sensitivity can be improved).

Response:

Thank you for the constructive comments from the reviewer. We have mention the limitations in the abstract

Action:

Abstract—This research proposes a tagging antenna sensor for permittivity detection of solid materials based on a close quarter approach. The sensor is proposed to operate at a frequency of 2.53 GHz using a single port resonator with a reflection coefficient (S_{11}) ≤ -10 dB. The sample is placed directly in the sensing area of the antenna sensor based on the concentration of the electric field. Permittivity detection is proposed based on the resonant frequency shift of the transmission coefficient (S_{21}) using interrogator antennas separated by a distance of (d) = 100 mm determined using the Fresnel region. Based on the measurement results, the antenna sensor has a high accuracy of 96% while the sensitivity and ΔF are 0.39% and 0.012 GHz respectively. ***Moreover, the sensitivity of proposed sensor is still low due the low concentration of the electric field. Therefore, increasing the sensitivity of the antenna sensor can be recommended as further work such as combining the structure of single port resonator with another structure such as interdigital capacitor and artificial magnetic conductor (AMC).*** *Finally, this research makes a significant contribution to the permittivity detection of solid materials with a close quarter approach to support real time and flexible measurements and can be recommended for several applications for the biomedical, pharmaceutical and material quality control industries.*

Keywords: *antenna sensor, close quarters, tagging detection, solid materials, permittivity*

Reviewer 3's Comments:

This study introduces a novel antenna sensor for permittivity detection of solid materials, leveraging resonance frequency shifts to determine permittivity through polynomial curve fitting. The proposed sensor achieves a high accuracy of 96% (Table 2) but exhibits limited sensitivity due to suboptimal E-field concentration. Validation against probe sensors demonstrates its potential for biomedical, pharmaceutical, and material quality control applications However, several aspects require further refinement:

Comment#1:

Limited Discussion on Sensitivity – The paper attributes the sensor's low sensitivity (0.39%) to insufficient E-field concentration but lacks further analysis or improvement strategies. A discussion on optimizing the antenna structure or measurement conditions would strengthen this section.

Response:

Thank you for the constructive comments from the reviewer. We have provided suggestions to improve the sensitivity of proposed sensor with combining single port resonator with Interdigital Structure (IDC) [24] and Artificial Magnetic Coupled resonator [25] as sensing area with high concentrations of electric field.

Action:

Furthermore, validation of this work was carried out by comparing the performance of the proposed antenna sensor with the microwave sensor proposed in previous work as shown in Table 3. The performance of the sensors compared included resonance frequency, sample type, permittivity range, accuracy, sensitivity and capability for tagging detection with a close quarter approach.

Previous work [13][14][15][16] proposed microwave sensors for permittivity detection of solid materials using Dual SRR, Nested SRR, T-ring resonator and interdigital structure. However, the proposed work is not capable of tagging detection over a certain distance. Table 3 shows that the main contribution of this work is producing an antenna sensor that has the capability for tagging detection using a close quarter approach based on frequency shift for solid material characterization. Moreover, the proposed antenna sensor has a high accuracy of 96% for the permittivity range 1 - 4.13. However, the sensitivity of the antenna sensor is still small because the E-field is not optimally concentrated. Therefore, increasing the sensitivity of the antenna sensor can be recommended as further work such as combining the structure of single port resonator with interdigital capacitor (IDC) structures [24] or using artificial magnetic coupled (AMC) as sensing area with high concentrations of electric field [25].

Reference for improving sensitivity of proposed sensor

[24] S. Alam *et al.*, "High Stability Single-Port Dual Band Microwave Sensor Based on Interdigital Capacitor Structure with Asymmetry Branch Feedline," *IEEE Access*, vol. 13, no. January, 2025, doi: 10.1109/ACCESS.2025.3538042.

[25] W. J. Wu and G. Wang, "A modified AMC-based antenna sensor for contactless measurement of complex permittivity," *Meas. J. Int. Meas. Confed.*, vol. 206, no. June 2022, p. 112261, 2023, doi: 10.1016/j.measurement.2022.112261.

Comment#2

Equations (11) and (12) are crucial for permittivity calculation, yet their derivations are omitted. Providing additional explanations would improve transparency and credibility.

Response:

Thank you for the constructive comments from the reviewer. We have explained in our paper that the Equation (11) represents the correlation between permittivity and resonance frequency obtains a fitting curve using polynomial order. The permittivity of the sample is extracted based on fitting curve with a polynomial equation by observing the resonance frequency of the antenna sensor and the permittivity of the sample[23]. Moreover, Equation (12) represents the sensitivity of the proposed sensor where ΔF is the difference between the unloaded frequency and the loaded frequency of the sensor antenna for each sample, while $\Delta\varepsilon_r$ is the difference between the sample permittivity and the vacuum condition where $\varepsilon_r = 1$ as a reference[23].

Action:

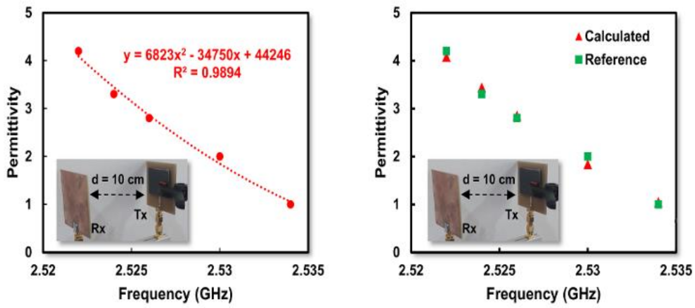

Figure 8. (a) Fitting curve for permittivity detection, (b) comparison permittivity from calculation and reference

Based on **Figure 8(a)**, the correlation between permittivity and resonance frequency obtains a fitting curve with $R^2 = 0.98$. These results show that the equation obtained has high accuracy to determine the permittivity of samples. Furthermore, the permittivity of the sample can be determined using the following equation:

$$\varepsilon_r = 6823fr^2 - 34750fr + 4426 \qquad (11)$$

where ε_r is the permittivity of the sample and f_r is the resonance frequency of the antenna sensor for four types of materials with different permittivity. The accuracy of permittivity detection using an antenna sensor and comparison with detection using a sensor probe is shown in **Figure 8(b)** and **Table 2**.

Table 2. Comparison measurements from antenna sensor and probe sensors

Samples	Permittivity		Error (%)	Accuracy (%)
	Probe sensor	Antenna sensor		
Vacuum	1.05	1.02	2.7	97.31
Polystyrene	1.84	2.02	8.9	91.12
Polypropylene	2.85	2.82	1.1	98.85
PVC	3.44	3.32	3.6	96.38
Rubber	4.08	4.12	0.9	99.09

Table 2 shows that the proposed antenna sensor has high accuracy for permittivity detection of the four solid materials with a range of 91% - 99%. Moreover, errors from measurement process arise from multiple sources, including calibration inaccuracies, environmental factors, and sensor design limitations. To minimize these errors, advanced calibration techniques, shielding from environmental interference, and improved sensor designs incorporating robust signal processing methods are essential.

In addition, the sensitivity (S) of the antenna sensor can be determined based on the following equation[23]:

$$S = \frac{\Delta F}{\Delta\, \varepsilon_r} \times 100\% = \frac{f_{loaded} - f_{unloaded}}{\varepsilon_r\, samples - \varepsilon_r\, vacuum} \times 100\% \qquad (12)$$

where ΔF is the difference between the unloaded frequency and the loaded frequency of the sensor antenna for each sample, while $\Delta\varepsilon_r$ is the difference between the sample permittivity and the vacuum condition where $\varepsilon_r = 1$ as a reference.

Reference:

[23] S. Alam, Z. Zakaria, I. Surjati, N. A. Shairi, M. Alaydrus, and T. Firmansyah, "Dual-Band Independent Permittivity Sensor Using Single-Port with a Pair of U-Shaped Structures for Solid Material Detection," *IEEE Sens. J.*, vol. 22, no. 16, pp. 16111–16119, 2022, doi: 10.1109/JSEN.2022.3191345.

Comment#3

Table 3 compares methods but does not emphasize the unique advantages of the proposed sensor, such as cost-effectiveness or usability improvements

Response:

Thank you for the constructive comments from the reviewer. We have added comparison of design complexity of proposed sensor with previous work. In this paper, the main contribution of this work is producing an antenna sensor that has the capability for tagging detection using a close quarter approach based on frequency shift for solid material characterization. Finally, this research can be recommended for permittivity detection in solid materials in real time for several applications including biomedical, pharmaceutical and material quality control.

Action:

Table 3. Comparison proposed antenna sensor with existing works

Ref.	Method	f_r (GHz)	Permittivity range	Samples	Sensing parameter	Sensing performance			Tagging detection	Close quarter approach	Design complexity
						ΔF (GHz)	Acc. (%)	Sens. (%)			
[13]	Dual SRR	2.27	1 – 4.3	Solid	Freq. shift	0.29	85%	8.52	No	No	Moderate
[14]	Nested CSRR	3.37	1 – 4.3	Solid	Freq. shift	0.47	87%	14.02	No	No	High
[15]	T-ring resonator	4.2	1 – 4.3	Solid	Freq. shift	0.18	95%	5.45	No	No	Moderate
[16]	Interdigital structure	5.65	1 – 4.3	Solid	Freq. shift	0.17	98%	3.25	No	No	High
This work	Antenna with U -slot	2.53	1 – 4.13	Solid	Freq. shift	0.012	96%	0.39	Yes	Yes	Low

Previous work [13][14][15][16] proposed microwave sensors for permittivity detection of solid materials using Dual SRR, Nested SRR, T-ring resonator and interdigital structure. However, the proposed work is not capable of tagging detection over a certain distance and the structure is more complex to fabricate. **Table 3** shows that the main contribution of this work is producing an antenna sensor that has the capability for tagging detection using a close quarter approach based on frequency shift for solid material characterization. Moreover, the proposed antenna sensor has a high accuracy of 96% for the permittivity range 1 - 4.13. However, the sensitivity of the antenna sensor is still small because the E-field is not optimally concentrated. Therefore, increasing the sensitivity of the antenna sensor can be recommended as further work such as combining the structure of single port resonator with interdigital capacitor (IDC) structures [24] or using artificial magnetic coupled (AMC) as sensing area with high concentrations of electric field[25]. Finally, the proposed tagging permittivity sensors have a wide range of real-world applications, particularly in material identification, quality control, and environmental monitoring. These sensors utilize changes in permittivity to detect and differentiate materials in industries such as agriculture, food processing, and biomedical sensing. For instance, in agriculture, tagging permittivity sensors can monitor soil moisture content, ensuring optimal irrigation management. In the food industry, they help assess the freshness and composition of packaged goods by detecting changes in dielectric properties. In biomedical applications, these sensors can be integrated into wearable devices to monitor physiological parameters such as hydration levels and tissue properties.

Comment#4

While the paper mentions potential applications, a more in-depth discussion on real-world deployment and industrial feasibility would add value.

Response:

Thank you for the constructive comments from the reviewer. Tagging permittivity sensors have a wide range of real-world applications, particularly in material identification, quality control, and environmental monitoring. These sensors utilize changes in permittivity to detect and differentiate materials in industries such as agriculture, food processing, and biomedical sensing. For instance, in agriculture, tagging permittivity sensors can monitor soil moisture content, ensuring optimal irrigation management. In the food industry, they help assess the freshness and composition of packaged goods by detecting changes in dielectric properties. In biomedical applications, these sensors can be integrated into wearable devices to monitor physiological parameters such as hydration levels and tissue properties. We have mentioned the real-world applications of proposed sensor in the revised manuscript

Action:

Previous work [13][14][15][16] proposed microwave sensors for permittivity detection of solid materials using Dual SRR, Nested SRR, T-ring resonator and interdigital structure. However, the proposed work is not capable of tagging detection over a certain distance and the structure is more complex to fabricate. **Table 3** shows that the main contribution of this work is producing an antenna sensor that has the capability for tagging detection using a close quarter approach based on frequency shift for solid material characterization. Moreover, the proposed antenna sensor has a high accuracy of 96% for the permittivity range 1 - 4.13. However, the sensitivity of the antenna sensor is still small because the E-field is not optimally concentrated. Therefore,

increasing the sensitivity of the antenna sensor can be recommended as further work such as combining the structure of single port resonator with interdigital capacitor (IDC) structures [24] or using artificial magnetic coupled (AMC) as sensing area with high concentrations of electric field[25]. Finally, the proposed tagging permittivity sensors have a wide range of real-world applications, particularly in material identification, quality control, and environmental monitoring. These sensors utilize changes in permittivity to detect and differentiate materials in industries such as agriculture, food processing, and biomedical sensing. For instance, in agriculture, tagging permittivity sensors can monitor soil moisture content, ensuring optimal irrigation management. In the food industry, they help assess the freshness and composition of packaged goods by detecting changes in dielectric properties. In biomedical applications, these sensors can be integrated into wearable devices to monitor physiological parameters such as hydration levels and tissue properties.

UNIVERSITAS TRISAKTI

Assoc. Prof. Syah Alam S Pd, MT, PhD <syah.alam@trisakti.ac.id>

PIER Journals 25010701: Please pay attention to the following issues in your next revised version.

1 message

PIER Editorial and Production OFFICE <noreply@service.jpier.org.cn> Thu, Mar 6, 2025 at 7:32 PM
Reply-To: JPIER OFFICE <work@jpier.org>
To: syah.alam@trisakti.ac.id

Dear Dr. Syah Alam:

Title: Close Quarters Permittivity Detection Based on Tagging Antenna Sensor for Solid Material Characterization
by
Syah Alam, Indra Surjati, Raden Deiny Mardian, Lydia Sari, Ghathfan Daffin, Iznih, Zahriladha Zakaria, Leni Devera Asrar, Teguh Firmansyah

Figs.2(e)&6(e) have not been mentioned in the text. Please improve this in the next revision stage.

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Penina Xie

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Dear

Associate Editor of PIERS Journal March 06, 2025

SUBMISSION OF REVISED MANUSCRIPT

Dear Professor,

Thank you for giving me the opportunity to submit a revised draft of manuscript *Close Quarters Permittivity Detection Based on Tagging Antenna Sensor for Solid Material Characterization* (Manuscript ID: 25010701).

We appreciate the time and effort that you and the reviewers have dedicated to providing your valuable feedback on my manuscript to be published as a research paper in the PIERS Journal.

We are grateful to the reviewers for their insightful comments on my paper. We have been able to incorporate changes to reflect most of the suggestions provided by the reviewers. We have highlighted *(red marker)* the changes within the manuscript.

We look forward to receiving your communication.

Yours sincerely,

Syah Alam*

Please address all correspondence to:

Syah Alam

Department of Electrical Engineering, Universitas Trisakti

*Corresponding author e-mail: syah.alam@trisakti.ac.id

Editor Comments:

Figs.2(e)&6(e) have not been mentioned in the text. Please improve this in the next revision stage.

Response:

Thank you for the constructive comments from the reviewer. We have added revisions regarding the explanations for figure 2(e) and figure 6(e) in the revised paper.

Action:

Explanation about Figure 2 (e)

Model 1 is shown with a microstrip antenna with a rectangular patch connected to port 1 using a microstrip line. Furthermore, inset feed and inverted U-shaped slots are proposed to improve the performance of the antennas represented by model 2 and model 3. The overall model development and electric field concentration of the proposed sensor antenna are shown in ***Figure 2(a)***, ***Figure 2(b)*** *and* ***Figure 2(c)***.

Figure 2(a), ***Figure 2(b)*** *and* ***Figure 2(c)*** *show that the proposed sensor antenna has a maximum electric field in the range of 0.05 - 1.75 kV/m at the center and edge of the patch at a resonance frequency of 2.4 GHz. Furthermore, the simulation results of S_{11} with the addition of an inset feed and an inverted U-shaped slot are shown in* ***Figure 2 (d)***. *Based on the simulation results, the S_{11} of the proposed antenna with model 1 is still ≥ -10 dB, while for model 2 and model 3 antennas it is ≤ -10 dB. These findings indicate that the addition of an inset feed and an inverted U-shaped slot successfully improves the performance of the S_{11} of the proposed antenna.* ***In addition, the radiation pattern of the proposed antenna is shown in Figure 2(e) where model 3 has more optimal radiation compared to model 1 and model 2.***

Explanation about Figure 6 (e)

Based on the simulation results, the sensor can detect the permittivity of the sample for the distance range d = 5 cm - 15 cm as shown in ***Figure 6 (a)***, ***Figure 6 (b)*** *and* ***Figure 6 (c)***. *Furthermore, the correlation of the resonance frequency and permittivity is shown in* ***Figure 6 (d)*** *where the performance of the sensor is stable enough to detect the permittivity of the sample for the range d = 5 cm - 10 cm. The simulation results show that the resonance frequency shifts from 2.408 GHz to 2.401 GHz for d = 5 cm while for d = 10 cm it shifts from 2.406 GHz to 2.398 GHz and for d = 15 cm it shifts from 2.406 GHz to 2.397 GHz.* ***Other findings show that the distance between the sensor and the interrogator antenna greatly affects the transmission coefficient (S_{21}) of the antenna where a long distance causes the transmission coefficient of the sensor to shift to low. The simulation results show that the S_{21} of the proposed sensor shifts from -9.45 dB to -15.41 dB and -20.99 dB for the distance range d = 5 cm - 10 cm as shown in Figure 6 (e). This finding indicates that the distance between the sensor and the interrogator antenna should be determined based on the fresnel region. Therefore, in this paper, the distance between the sensor and the antenna is determined based on the Fresnel region which is represented by $d = 2D^2/\lambda$.***

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Assoc. Prof. Syah Alam S Pd, MT, PhD <syah.alam@trisakti.ac.id>

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1 message

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To: syah.alam@trisakti.ac.id

Dear Dr. Syah Alam:

The Editorial Board has recommended, based on considerations of topical relevance, page budget of the journals, review inputs, time constraint for publication, etc., that your article
Key: 25010701
Title: Close Quarters Permittivity Detection Based on Tagging Antenna Sensor for Solid Material Characterization

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Yours sincerely

Penina Xie

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Dear

Associate Editor of PIERS Journal **March 18, 2025**

SUBMISSION OF REVISED MANUSCRIPT

Dear Professor,

Thank you for giving me the opportunity to submit a revised draft of manuscript Close Quarters Permittivity Detection Based on Tagging Antenna Sensor for Solid Material Characterization (Manuscript ID: 25010701).

We appreciate the time and effort that you and the reviewers have dedicated to providing your valuable feedback on my manuscript to be published as a research paper in the PIERS Journal.

We are grateful to the reviewers for their insightful comments on my paper. We have confirmed several questions from the editor regarding our proposed paper.

We look forward to receiving your communication.

Yours sincerely,

Syah Alam*

Please address all correspondence to:

Syah Alam

Department of Electrical Engineering, Universitas Trisakti, DKI Jakarta, Indonesia

*Corresponding author e-mail: syah.alam@trisakti.ac.id

Comment#1:

Please provide the full name for RSSI.

Response:

Thank you for your constructive comments. Therefore, we convey the full form of the abbreviation **RSSI**, which is *Received Signal Strength Indication*.

Comment#2:

In the first paragraph of section 2 "The distance of Tx and Rx is determined based on the Fresnel region of the proposed antenna," do you mean the distance between Tx and Rx? Otherwise, what is distance about?

Response:

Thank you for your constructive comments. In this paper, we proposed antenna sensor for close quarters permittivity detection of solid materials. The distance Tx and Rx represented the distance between Tx and Rx in the measurement process using a vector network analyzer. The distance between Tx and Rx is determined based on the Fresnel region of the proposed antenna which is represented by $d = 2D^2/\lambda$ or approximately 10 cm.

Comment#3:

In the second paragraph of section 4.1 "Measurement setup for permittivity detection with a tagging antenna sensor with a distance of d=10 cm where the sample is placed on the Tx antenna which is connected to port 1 while for the Rx antenna it is connected to port 2 as shown in Figure 7(a)," if "Measurement setup" is the main sentence's subject, what is the predicate verb for the main sentence?

Response:

Thank you for your constructive comments. We agree with the editor comment. Therefore, we change the sentence to: *"The measurement process for permittivity detection of solid samples using VNA with a tagging antenna sensor is proposed using VNA where the two antennas are separated with a distance of d=10 cm where the sample is placed on the Tx antenna which is connected to port 1 while for the Rx antenna it is connected to port 2 as shown in Figure 7(a)"*

Comment#4:

In the abstract, AMC is defined as artificial magnetic conductor, but in the right column of page 7, AMC becomes artificial magnetic coupled.

Response:

Thank you for your constructive comments. We agree with the editor comment. Therefore, we confirm that AMC is an *artificial magnetic conductor*.