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05-Dec-2024

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Your manuscript entitled "High Stability Single-Port Dual Band Microwave Sensor Based on Interdigital Capacitor Structure with Asymmetry Branch Feedline" has been successfully submitted online and is presently being given full consideration for publication in IEEE *Access*.

If you are receiving this email, that means you are listed as an author. If you do **not** approve of being listed as a co-author on this article, please reach out to ieeeaccesseic@ieee.org as soon as possible.

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Thank you again for submitting your manuscript to IEEE *Access*.

Sincerely,

IEEE *Access* Editorial Office

Decision letter (Initial Submission)

IEEE Access - Decision on Manuscript ID Access-2024-48908

×

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To: syah.alam@trisakti.ac.id, indra@trisakti.ac.id, lydia_sari@trisak.ac.id, deiny.wp@gmail.com, r.deiny@ui.ac.id, deiny_wp@trisakti.ac.id, teguhfirmansyah@untirta.ac.id, muh.iqbal@itb.ac.id, lamet_ae39@apps.ipb.ac.id, mudrikalaydrus@mercubuana.ac.id, zahriladha@utem.edu.my
CC: wsh.zhao@gmail.com

19-Dec-2024

Dear Dr. Alam:

I am writing to you regarding manuscript # Access-2024-48908 entitled "High Stability Single-Port Dual Band Microwave Sensor Based on Interdigital Capacitor Structure with Asymmetry Branch Feedline" which you submitted to IEEE *Access*.

Your article was peer reviewed with interest but has not been recommended for publication in its current form. We strongly encourage you to address the reviewers' concerns, which can be found at the bottom of this letter, and resubmit your article to IEEE *Access* once you have updated it accordingly.

Please note that IEEE *Access* has a binary peer review process. Therefore, to uphold quality to IEEE standards, an article is rejected even if it requires minor edits.

When updating your manuscript, you should elaborate on your points and clarify with references, examples, data, etc. If you disagree with any technical points the reviewers have made, please include your counterarguments in your response to the reviewers (more information detailed below) and work this into the updated manuscript.

Also, note that if a reviewer suggested references, you should only add those that are relevant to your work if you feel they strengthen your article. Recommending references to specific publications is not appropriate for reviewers and you should report excessive cases to ieeeaccessEIC@ieee.org. Authors are not obligated to cite articles that are recommended by the reviewers, and the final decision on the article will not be influenced by whether or not authors cite these suggested references.

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Upon resubmission you will be asked to upload the following 3 files:

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****IMPORTANT:** Please see the attached Resubmission Checklist that details all the items listed above. Please utilize this checklist to ensure you have made the necessary edits to your manuscript, and to ensure you have all the necessary files prepared prior to resubmission.

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We sincerely hope you will update your manuscript and resubmit soon. Please contact me if you have any questions.

Thank you for your interest in IEEE *Access*.

Sincerely,

Prof. Wen-Sheng Zhao
Associate Editor, IEEE *Access*
wsh.zhao@gmail.com

Reviewers' Comments to Author:

Reviewer: 1

Comments:
The explanation of the paper is good. However, I don't think the prototype described in the paper is a sensor. To me, it appears to be an antenna (single port) designed for multiband operations. Additionally, in Figure 6(c), it seems that the antenna incorporates a superstrate for gain enhancement applications.

Additional Questions:
Please confirm that you have reviewed all relevant files, including supplementary files and any author response files, which can be found in the "View Author's Response" link above (author responses will only appear for resubmissions): Yes, all files have been reviewed

1) Does the paper contribute to the body of knowledge?: Yes

2) Is the paper technically sound?: Yes

3) Is the subject matter presented in a comprehensive manner?: Yes

4) Are the references provided applicable and sufficient?: Yes

5) Are there references that are not appropriate for the topic being discussed?: Yes

5a) If yes, then please indicate which references should be removed.:

Reviewer: 2

Comments:
The characterization of solid material permittivity at dual frequencies using a dual-band resonator sensor, with improved stability and high performance, presented in this manuscript is intriguing. Therefore, I recommend considering the publication of this work in IEEE Access, with some suggested improvements.
Please take the following comments into account to enhance the quality of your manuscript:
1. Include expressions that help estimate the dual-band resonant frequencies using the proposed IDC resonator structure.
2. How did you calculate the component values in the equivalent circuit?
3. Please consider adding the following relevant works in the literature review of the introduction and comparison table.
"High-Accuracy Complex Permittivity Characterization of Solid Materials Using Parallel Interdigital Capacitor- Based Planar Microwave Sensor."
10.1109/JSEN.2020.3041014
"Design and Optimization of Interdigitated Microwave Sensor for Multidimensional Sensitive Characterization of Solid Materials."
10.1109/JSEN.2021.3105410

Additional Questions:
Please confirm that you have reviewed all relevant files, including supplementary files and any author response files, which can be found in the "View Author's Response" link above (author responses will only appear for resubmissions): Yes, all files have been reviewed

1) Does the paper contribute to the body of knowledge?: Yes

2) Is the paper technically sound?: Yes

3) Is the subject matter presented in a comprehensive manner?: Yes

4) Are the references provided applicable and sufficient?: Can be improved.

5) Are there references that are not appropriate for the topic being discussed?: No

5a) If yes, then please indicate which references should be removed.:

If you have any questions, please contact article administrator: Ms. Suhasini Das
das.suhasini@ieee.org

Original Manuscript ID: *Access-2024-4890*

Original Article Title: *"High Stability Single-Port Dual Band Microwave Sensor Based on Interdigital Capacitor Structure with Asymmetry Branch Feedline"*

To:

Prof. Wen-Sheng Zhao

Associate Editor, IEEE Access

Re: Response to reviewers

Dear Editor,

Thank you for allowing the resubmission of our manuscript, with an opportunity to address the reviewers' comments.

We are uploading (a) our point-by-point response to the comments (below) (response to reviewers, under "Author's Response Files"), (b) an updated manuscript with yellow highlighting indicating changes (as "Highlighted PDF"), and (c) a clean updated manuscript without highlights ("Main Manuscript").

Best regards,

Syah Alam, et al.

Please address all correspondence to:

Syah Alam* / Zahriladha Zakaria**

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** Faculty of Electronic and Computer Technology and Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Malaysia

Corresponding author e-mail: *syah.alam@trisakti.ac.id / ** zahriladha@utem.edu.my

Reviewer#1

Concern # 1:

The explanation of the paper is good. However, I don't think the prototype described in the paper is a sensor. To me, it appears to be an antenna (single port) designed for multiband operations. Additionally, in Figure 6(c), it seems that the antenna incorporates a superstrate for gain enhancement applications.

Author response:

We thank the reviewer for constructive comments. We agree with the reviewer's comment that the proposed resonator can also function as an antenna due to its single port configuration. However, based on the simulation results, the proposed resonator has low performance as an antenna as shown in **Fig. 1 (a)** and **Fig. 1 (b)**.

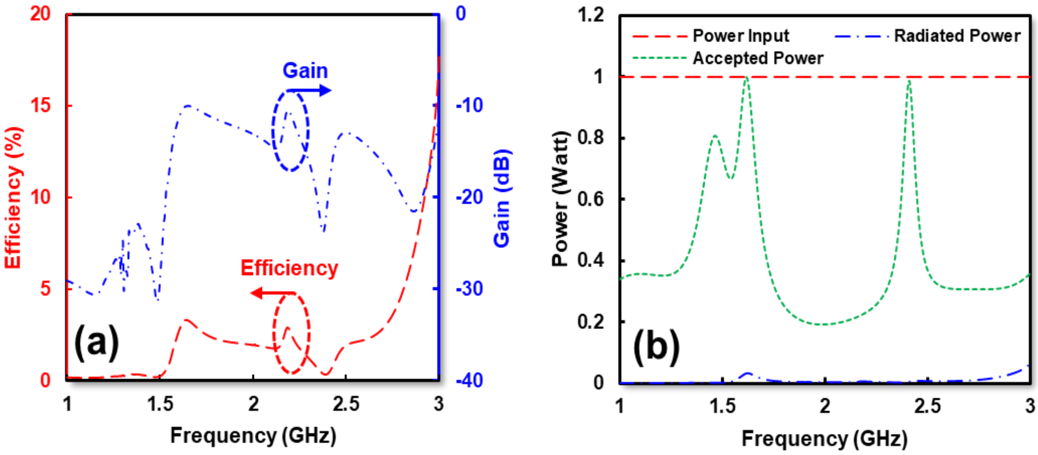


Fig. 1 Simulation result of single port resonator, (a) efficiency and gain of proposed resonator, (b) comparison between input, accepted dan transmitted power of proposed resonator

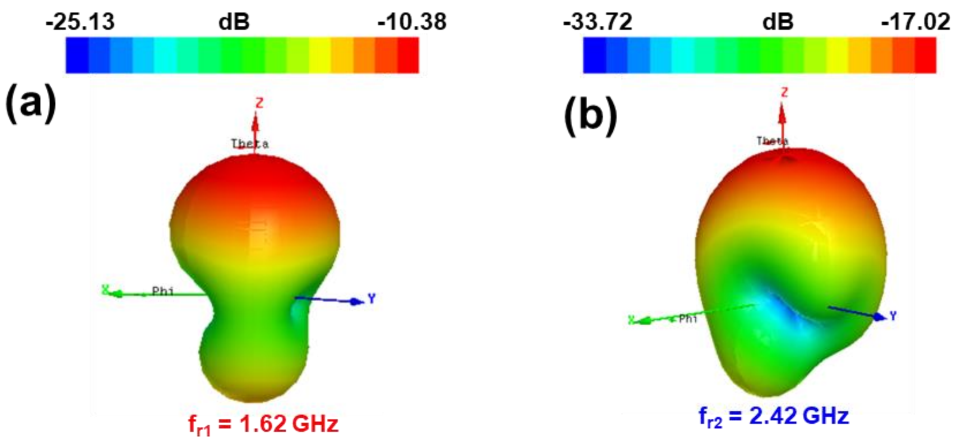


Fig. 2 Simulation result of radiation pattern, (a) radiation pattern at f_{r1} = 1.62 GHz, (b) radiation pattern at f_{r2} = 2.42 GHz

Fig. 1 (a) shows that the proposed resonator has low efficiency at f_{r1} = 1.61 GHz and f_{r2} = 2.42 GHz of 3.04% and 0.68%, respectively. In addition, the gain of proposed resonator is also very low where for f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz it is -10.37 dB and -16.63 dB, respectively. Furthermore, the ratio between the input power, received power and transmitted power of the proposed resonator is also very low as shown in **Fig. 1 (b)**. From the simulation results, the default input power is 1 watt while the transmitted power for f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz is 0.98 watt and 0.97 watt. However, the transmitted power is very low where for f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz is 0.03 watt and 0.006 watt, respectively. Furthermore, the radiation pattern of the proposed resonator is shown in **Fig. 2 (a)** and **Fig. 2 (b)** where for f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz has a maximum gain of -10.38 dB and -17.02 dB. This finding indicates that the proposed resonator has low performance as an antenna due to low efficiency and gain. Since the performance of the proposed resonator is not functioning as an antenna, this structure is more suitable for microwave sensor.

In this work, the sensor is designed to detect the permittivity of the sample by observing the interaction between the electric field and the permittivity of the sample used. The resonator surface that has a high electric field (E-field) can be recommended as the sensing area used to place the sample. The sample used is a dielectric sample that does not contain metal.

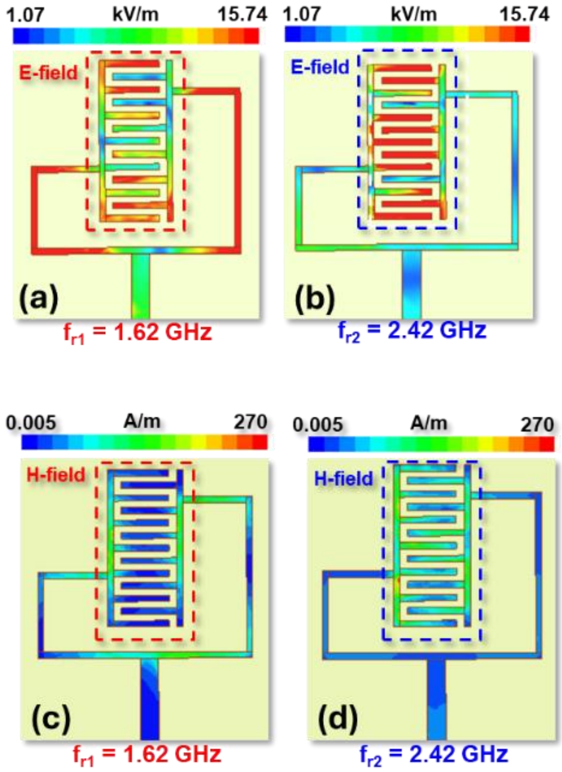


Fig.3. E-field and H-field simulations; (a) E-field at f_{r1} = 1.62 GHz, (b) E-field at f_{r2} = 2.41 GHz, (c) H-field at f_{r1} = 1.62 GHz, (d) H-field at f_{r2} = 2.42 GHz

Furthermore, the electric field and magnetic field concentrations of the IDC-based resonator are shown in Fig.3 (a), **Fig.3 (b)**, **Fig.3 (c)** and **Fig.3 (d)**. Furthermore, **Fig. 3 (a)** and **Fig. 3 (b)** show that the highest electric field concentration of the proposed resonator at f_{r1}=1.62 GHz and f_{r2}= 2.42 GHz is on the IDC surface of the proposed sensor with a range of 1.07 – 15.74 kV/m. In contrast, the magnetic field concentration of the proposed resonator at f_{r1}=1.62 GHz and f_{r2}= 2.42 GHz are very low and is in the range of 0.005 – 270 A/m. These findings indicate that the IDC surface has a high electric field and a low magnetic field so that it becomes a potential location as a sensing area that can be recommended to place samples to be detected. It also shows that the application of the IDC structure has successfully confined the electric field and reduced the magnetic field in the proposed sensor. Therefore, we propose the single port resonator as a microwave sensor for permittivity detection of solid materials.

Author action: We updated the manuscript by adding simulation data of the gain, efficiency and radiation pattern of the proposed single port resonator which is represented by **Fig. 4** and **Fig. 5** in the revised paper.

*Kindly refer to: Section II. WORKING PRINCIPLE OF PROPOSED SENSOR, Sub-section B. STRUCTURE OF PROPOSED IDC RESONATOR USING ASYMMETRY BRANCH FEED LINE, **Fig.4** and **Fig.5** page 3.*

A. STRUCTURE OF PROPOSED IDC RESONATOR USING ASYMMETRY BRANCH FEED LINE

The proposed microwave sensor is designed using FR-4 substrate type with dielectric constant (ε_r) 4.3, loss tan (tan α) 0.0265 and thickness (h) 1.6 mm. The microwave sensor is designed using a single-port resonator operating at two different resonant frequencies f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz. To produce dual frequencies, the resonator is connected with RP-SMA connector with impedance of 50 Ω using dual-feed approach.

In addition, to increase the electric field concentration of the resonator, interdigital capacitor (IDC) structure is proposed as a solution. **Fig. 2 (a)** shows the dimensions of the proposed sensor. Furthermore, **Fig. 2 (b)** shows the structure of the proposed sensor where the sensor is designed using a PCB with two copper layers while the upper layer of the PCB is used to place the sensor made of copper and the lower layer is used as a ground plane.

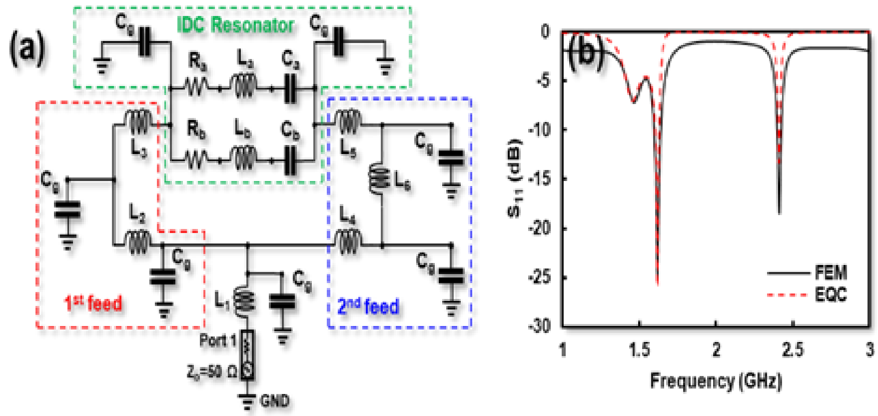


Fig.2. Modeling of the proposed sensor; (a) Equivalent circuit of the proposed sensor, (b) comparison of simulation results from FEM and EQC.

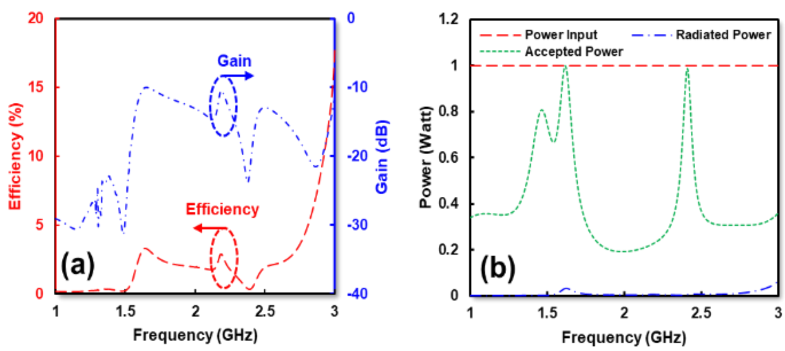


Fig. 3. Simulation result of single port resonator, (a) efficiency and gain of proposed resonator, (b) comparison between input, accepted dan transmitted power of proposed resonator

The simulation results of the proposed sensor are shown in **Fig. 2 (c)** where the sensor operates at two different resonant frequencies, namely f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz.

The dimensions of the proposed sensor are represented by W_g = 50 mm, L_g = 50 mm, W_s = 3.1 mm, L_z = 15 mm, L_a = 17.3 mm, L_b = 15.9 mm, W_s = 1 mm, L_c = 26.7 mm, L_d = 13.7 mm, L_e = 11.8 mm and L_f = 11.8 mm. Furthermore, the dimensions of the IDC structure are represented by W_i = 11.7 mm and L_i = 25 mm while the gaps in each IDC are represented by G_i = G_s = 1 mm. It should be noted that the width and length of the gap greatly affect the electric field concentration and the resonant frequency of the proposed sensor.

The performance in terms of gain and efficiency of the single port resonator are shown in **Fig. 3(a)** and **Fig. 3(b)**. Furthemore, **Fig. 3 (a)** shows that the proposed resonator has low efficiency at f_{r1} = 1.61 GHz and f_{r2} = 2.42 GHz of 3.04% and 0.68%, respectively. In addition, the gain of proposed resonator is also very low where for f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz it is -10.37 dB and -16.63 dB, respectively. Furthermore, the ratio between the input power, received power and transmitted power of the proposed resonator is also very low as shown in **Fig. 3 (b)**. From the simulation results, the default input power is 1 watt while the transmitted power for f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz is 0.98 watt and 0.97

watt. However, the transmitted power is very low where for f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz is 0.03

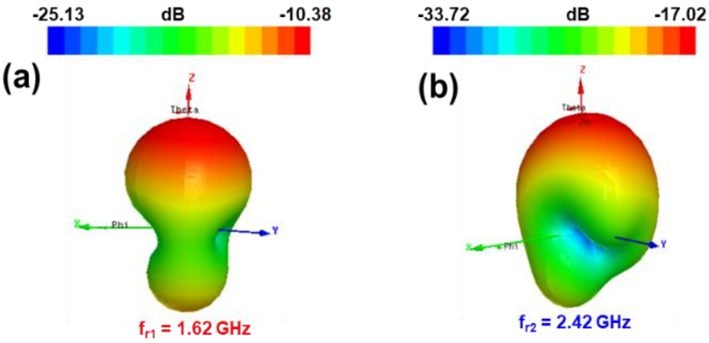


Fig. 4. Simulation result of radiation pattern, (a) radiation pattern at f_{r1} = 1.62 GHz, (b) radiation pattern at f_{r2} = 2.42 GHz

watt and 0.006 watt, respectively. Furthermore, the radiation pattern of the proposed resonator is shown in **Fig. 4 (a)** and **Fig. 4 (b)** where f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz have a maximum gain of -10.38 dB and -17.02 dB. This finding indicates that the proposed resonator has low performance as an antenna due to low efficiency and gain. This finding indicates that the proposed resonator has low performance to function as an antenna due to low efficiency and gain. Thus, this structure is more suitable for microwave sensors.

Reviewer#2

The characterization of solid material permittivity at dual frequencies using a dual-band resonator sensor, with improved stability and high performance, presented in this manuscript is intriguing. Therefore, I recommend considering the publication of this work in IEEE Access, with some suggested improvements.

Concern # 1:

Include expressions that help estimate the dual-band resonant frequencies using the proposed IDC resonator structure.

Author response:

We thank the reviewer for constructive comments. Next, to estimate the performance of the resonator having dual band characteristics, we propose a development model of the proposed resonator as shown in **Fig. 4**.

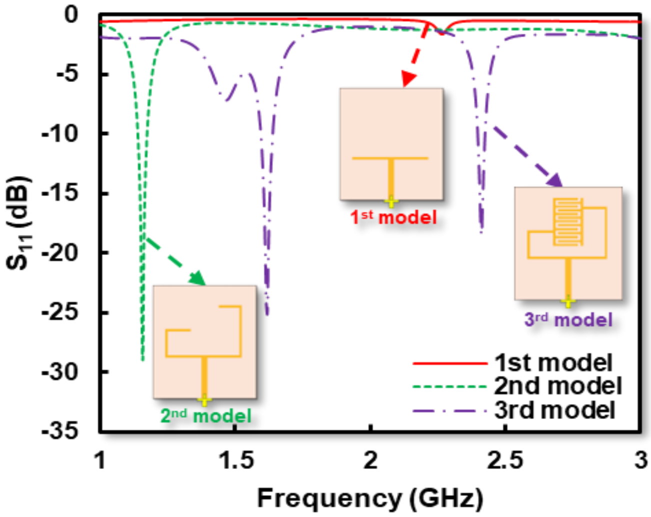


Fig.4. Development model of the proposed resonator, (a) 1st model, (b) 2nd model, (c) 3rd model

Fig.4 shows that the 1st model of the resonator is represented by a T-shaped resonator operating at a single band at a frequency of 2.26 GHz. Furthermore, the 2nd singzmodel is represented by a T-shaped connected with two open-ended inductive arms that function as branch lines that generate a single band resonant frequency of 1.16 GHz. The resonant frequency of the resonator moves to a lower frequency in line with the increase in the arm length of the resonator. In the third model, the IDC structure is connected with two open-ended inductive arms of the resonator that produce dual-band characteristics with f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz.

In addition, we have also presented the equivalent circuit of the resonator represented by R, L and C to demonstrate the dual band characteristics of the proposed resonator. The inductive arm is represented by the inductor (L) while the gap of the resonator is represented by the capacitor (C) and the resistor (R) represents the tan delta of the substrate. Overall, the resonant frequency of the resonator can be determined using the following equation:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

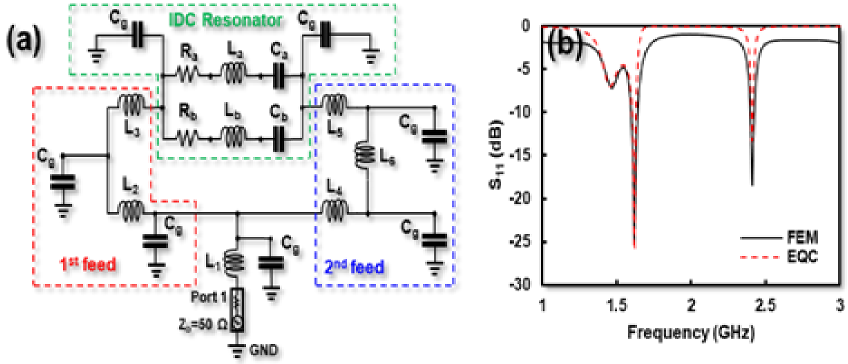


Fig 2. Modeling of the proposed sensor; (a) Equivalent circuit of the proposed sensor, (b) comparison of simulation results from FEM and EQC.

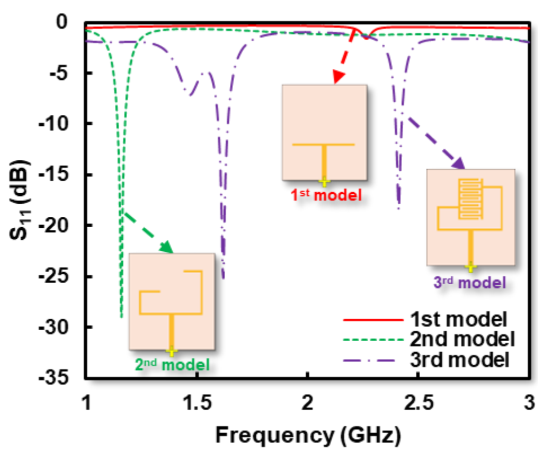
The proposed sensor can be modeled using an equivalent circuit (EQC) based on resistor (R), capacitor (C) and inductor (L) [26] as shown in **Fig. 2(a)**. The equivalent circuit of the proposed sensor is simulated using EM simulation and compared with Finite Element Modeling (FEM) as shown in **Fig. 2(b)**. Based on the equivalent circuit shown in **Fig. 2 (a)**, the feedline of the resonator is represented by L_1 = 14 nH which is connected to port 1 with an impedance of Z_0 = 50Ω. In this work, the asymmetric branch feedline is represented by L_2 = 15.3 nH and L_3 = 0.71 nH as the 1st arm while the 2nd arm is represented by L_4 = 0.000242 nH, L_5 = 20.89 nH and L_6 = 9.18 nH. In addition, the IDC resonator is represented by two resonators with series configuration connected in parallel where R_a = 0.027 kΩ, L_a = 41.97 nH, C_a = 805 pF while for R_b = 2.46 kΩ, L_b = 0.262 nH and C_b = 6.28 pF. To prevent short circuits, C_g = 1 pF is proposed as grounding.

Author action: We updated the manuscript by adding sub-section **II.A. Development model of proposed resonator** and **Fig. 1** which represents the simulation results of the development model for the proposed resonator. We have also presented the equivalent circuit of the proposed resonator represented by **Fig. 3** in the revised paper.

*Kindly refer to: Section II. WORKING PRINCIPLE OF PROPOSED SENSOR, Sub-section A. DEVELOPMENT MODEL OF PROPOSED RESONATOR, **Fig.1**, page 2 and **Fig. 3**, page 3.*

A. DEVELOPMENT MODEL OF PROPOSED RESONATOR

Furthermore, to estimate the performance of the resonator having dual band characteristics, a development model of the proposed resonator was represented as shown in **Fig. 1**. The 1st model of the resonator is represented by a T-shaped resonator operating at a single band at a frequency of 2.26 GHz. Furthermore, the 2nd model is represented by a T-shaped connected with two open-ended inductive arms that function as branch lines that generate a single band resonant frequency of 1.16 GHz. The resonant frequency of the resonator moves to a lower frequency in line with the increase in



the arm length of the resonator. In the 3rd model, the IDC structure is connected with two open-ended inductive arms of the resonator that produce dual-band characteristics with f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz.

Fig. 1. *Development model of proposed resonator, (a) 1st model, (b) 2nd model, (c) 3rd model*

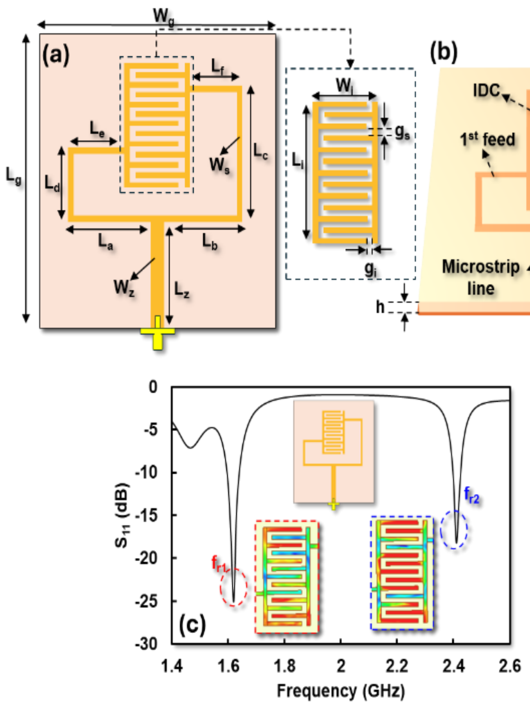


Fig. 2 *Model of the microwave sensor; (a) dimensions of the microwave sensor, (b) structure of the microwave sensor, (c) simulation of the reflection coefficient of the microwave sensor*

C. EQUIVALENT CIRCUIT MODEL OF PROPOSED RESONATOR

Next, the proposed sensor can be modeled using an equivalent circuit (EQC) based on resistor (R), capacitor (C) and inductor (L) [28] as shown in **Fig. 3 (a)**. The equivalent circuit of the proposed sensor is simulated using EM simulation and compared with Finite Element Modeling (FEM) as shown in **Fig. 3 (b)**. Based on the equivalent circuit shown in **Fig. 3 (a)**, the feedline of the resonator is represented by L_1 = 14 nH which is connected to port 1 with an impedance of Z_0 = 50Ω. In this work, the asymmetric branch feedline is represented by L_2 = 15.3 nH and L_3 = 0.71 nH as the 1st arm while the 2nd arm is represented by L_4 = 0.000242 nH, L_5 = 20.89 nH and L_6 = 9.18 nH. In addition, the IDC resonator is represented by two resonators with series configuration connected in parallel where R_a = 0.027 kΩ, L_a = 41.97 nH, C_a = 805 pF while for R_b = 2.46 kΩ, L_b = 0.262 nH and C_b = 6.28 pF. To prevent short circuits, C_g = 1 pF is proposed as grounding. Overall, the resonant frequency of the resonator can be determined using the following equation:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

Fig. 3 (b) shows that the simulation results of EQC and FEM have identical characteristics where the resonator operates in dual band with f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz. This finding indicates that the proposed equivalent circuit model has represented the working principle of the proposed resonator.

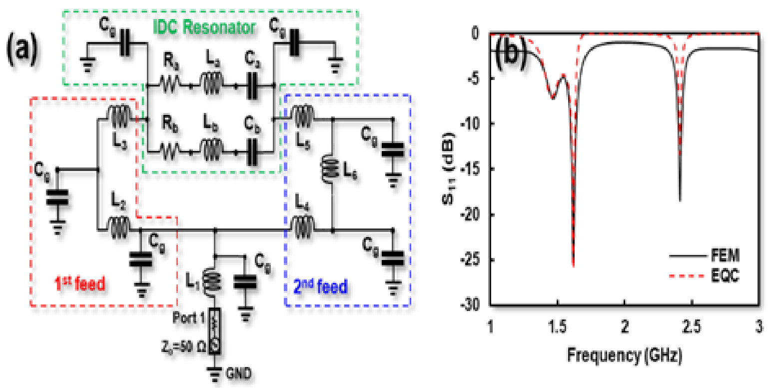


Fig 3. *Modeling of the proposed sensor; (a) Equivalent circuit of the proposed sensor, (b) comparison of simulation results from FEM and EQC.*

Concern # 2:

How did you calculate the component values in the equivalent circuit?

Author response:

We thank the reviewer for constructive comments. In this paper, we calculate and optimize the values of R, L and C components using AWR 2009 to represent the resonant frequency of the proposed resonator. The inductive arm is represented by the inductor (L) while the gap of the resonator is represented by the capacitor (C) and the resistor (R) represents the tan delta of the substrate. Overall, the resonant frequency of the resonator can be determined using the following equation [1]:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

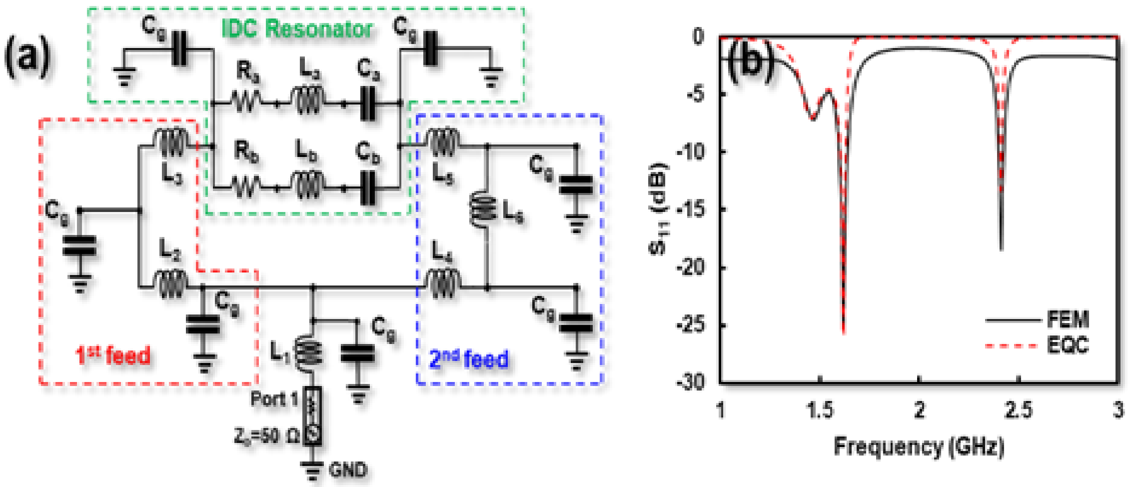


Fig 2. Modeling of the proposed sensor; (a) Equivalent circuit of the proposed sensor, (b) comparison of simulation results from FEM and EQC.

The proposed sensor can be modeled using an equivalent circuit (EQC) based on resistor (R), capacitor (C) and inductor (L) [26] as shown in **Fig. 2(a)**. The equivalent circuit of the proposed sensor is simulated using EM simulation and compared with Finite Element Modeling (FEM) as shown in **Fig. 2(b)**. Based on the equivalent circuit shown in **Fig. 2 (a)**, the feedline of the resonator is represented by L_1 = 14 nH which is connected to port 1 with an impedance of Z_0 = 50Ω. In this work, the asymmetric branch feedline is represented by L_2 = 15.3 nH and L_3 = 0.71 nH as the 1st arm while the 2nd arm is represented by L_4 = 0.000242 nH, L_5 = 20.89 nH and L_6 = 9.18 nH. In addition, the IDC resonator is represented by two resonators with series configuration connected in parallel where R_a = 0.027 kΩ, L_a = 41.97 nH, C_a = 805 pF while for R_b = 2.46 kΩ, L_b = 0.262 nH and C_b = 6.28 pF. To prevent short circuits, C_g = 1 pF is proposed as grounding.

Author action: We updated the manuscript by explaining the equivalent circuit of the proposed sensor

*Kindly refer to: Section II. WORKING PRINCIPLE OF PROPOSED SENSOR, Sub-section C. EQUIVALENT CIRCUIT MODEL OF PROPOSED RESONATOR., **Fig. 3**, page 3.*

C. EQUIVALENT CIRCUIT MODEL OF PROPOSED RESONATOR

Next, the proposed sensor can be modeled using an equivalent circuit (EQC) based on resistor (R), capacitor (C) and inductor (L) [28] as shown in **Fig. 3 (a)**. The equivalent circuit of the proposed sensor is calculated and simulated using AWR 2009 and compared with Finite Element Modeling (FEM) as shown in **Fig. 3 (b)**. Based on the equivalent circuit shown in **Fig. 3 (a)**, the feedline of the resonator is represented by L_1 = 14 nH which is connected to port 1 with an impedance of Z_0 = 50Ω. In this work, the asymmetric branch feedline is represented by L_2 = 15.3 nH and L_3 = 0.71 nH as the 1st arm while the 2nd arm is represented by L_4 = 0.000242 nH, L_5 = 20.89 nH and L_6 = 9.18 nH. In addition, the IDC resonator is represented by two resonators with series configuration connected in parallel where R_a = 0.027 kΩ, L_a = 41.97 nH, C_a = 805 pF while for R_b = 2.46 kΩ, L_b = 0.262 nH and C_b = 6.28 pF. To prevent short circuits, C_g = 1 pF is proposed as grounding. Overall, the resonant frequency of the resonator can be determined using the following equation[1]:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

Fig. 3 (b) shows that the simulation results of EQC and FEM have identical characteristics where the resonator operates in dual band with f_{r1} = 1.62 GHz and f_{r2} = 2.42 GHz. This finding indicates that the proposed equivalent circuit model has represented the working principle of the proposed resonator.

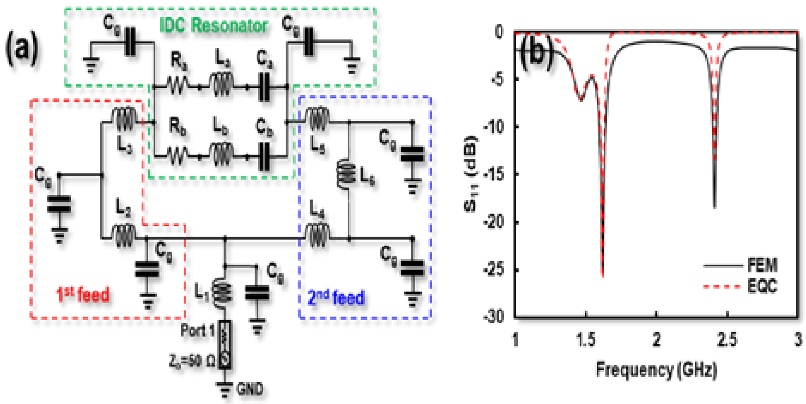


Fig 3. Modeling of the proposed sensor; (a) Equivalent circuit of the proposed sensor, (b) comparison of simulation results from FEM and EQC.

Reference:

[1] S. Alam, Z. Zakaria, I. Surjati, N. A. Shairi, M. Alaydrus, and T. Firmansyah, "Multifunctional of dual-band permittivity sensors with antenna using multicascode T-shaped resonators for simultaneous measurement of solid materials and data transfer capabilities," *Meas. J. Int. Meas. Confed.*, vol. 217, no. November 2022, p. 113078, 2023, doi: 10.1016/j.measurement.2023.113078.

Concern # 3:

Please consider adding the following relevant works in the literature review of the introduction and comparison table.

- *"High-Accuracy Complex Permittivity Characterization of Solid Materials Using Parallel Interdigital Capacitor- Based Planar Microwave Sensor." 10.1109/JSEN.2020.3041014*
- *"Design and Optimization of Interdigitated Microwave Sensor for Multidimensional Sensitive Characterization of Solid Materials." 10.1109/JSEN.2021.3105410*

Author response:

We thank the reviewer for constructive comments. We have included the following references in the literature review and comparison Table III.

Author action: We updated the manuscript by including the following references in the literature review and comparison table III

Kindly refer to: Section I. INTRODUCTION, page 1 and Table III. COMPARISON WITH PREVIOUS WORKS, page 9.

Microwave sensors (MS) have seen significant advancement in the evaluation of both solids and liquids due to their advantages, such as high precision, a high Q-factor, cost-effectiveness, and compactness [1]–[3]. One of the measurable properties using MS is permittivity, which reflects a material's ability to sustain an electric field. The permittivity of the material under test (MUT) can be determined via perturbation theory, assuming the MUT behaves as a capacitive load [4]–[6]. Several microwave sensors based on resonators like the Split Ring Resonator (SRR) [7]–[10], Complementary Split Ring Resonator (CSRR)[11]–[13], Substrate Integrated Waveguide (SIW) [14],[15], Interdigital Capacitor (IDC) [16]–[20], AMC [21],[22] have been developed for solid and liquid material assessment.
Previous work presented a single-port MS based on slot loaded [23] and dual U-shaped [24] for solid material characterization. Furthermore, another work proposed a dual-function permittivity sensor with an antenna using a single-port resonator for solid material characterization using an aperture coupling structure [25]. In addition, previous work [26] proposed a single-port microwave sensor based on dual T-shaped for contact and long-distance detection. The advantage of a single-port resonator-based microwave sensor is that it can also function as an antenna for data transmission[27].

TABLE III
COMPARISON WITH PREVIOUS WORKS

Ref.	Method	Freq (GHz)	Range of ε_r	Performance			Num. of port	Dual-band performance	Confined E-field region	Disturbance analysis effect	High stability performance
				Max. FDR (GHz)	Max NS. (%)	Max Acc. (GHz)					
[8]	SRR	0.39	1 – 7.33	0.102	1.625	98.20	1	-	Yes	-	-
[10]	SSRR with spurlines	2.22	1 – 4.40	0.030	1.340	98.36	2	-	Yes	-	-
[13]	CSRR	2.65	1 – 3.00	0.150	5.380	97.71	2	-	Yes	-	-
[19]	**IDC**	**2.65**	**1 – 6.15**	**0.373**	**4.300**	**99.99**	**2**	-	**Yes**	-	-
[20]	**IDC**	**2.35 / 5.79**	**1 – 10.5**	**0.150**	**3.980**	**99.99**	**2**	-	**Yes**	-	-
[21]	Artificial Magnetic Conductor	4.04	1 – 4.40	0.070	1.890	96.48	1	-	Yes	-	-
[23]	Slot-loaded patch	2.50	1 – 10.20	0.072	5.240	98.80	1	-	-	-	-
[24]	Dual U-shaped	1.20 / 2.10	1 – 4.30	0.007	1.150	99.02	1	Yes	Yes	-	-
[25]	Aperture coupling	9.54 / 12.30	1 – 12.50	0.078	0.640	92.30	1	Yes	Yes	-	-
[26]	Dual T-shaped with IDC	1.64 / 2.43	1 – 6.15	0.016	0.003	95.99	1	Yes	Yes	-	-
[32]	SRR	1.24 / 2.08	1 – 6.00	0.050	4.101	96.97	2	Yes	Yes	-	-
This work	**Asymmetric branch feed with IDC**	**1.61 / 2.52**	**1 – 6.15**	**0.110**	**4.330**	**95.98**	**1`**	**Yes**	**Yes**	**Yes**	**Yes**

A thorough evaluation comparing the proposed sensor's performance with previous studies is conducted, as detailed in **Table III**. A fair comparison with previous work is proposed by observing the performance of the sensor in terms of the method, permittivity range, resonance frequency (f_r), Frequency Detection Resolution (FDR), Normalized Sensitivity (NS) and accuracy. In addition, other performances that are compared are dual band characteristics, e-field localization, disturbance effect analysis and also high stability of the proposed sensor.

Previous work proposed a microwave sensor using a dual-port resonator for permittivity detection of solid materials based on SRR [8],[10],[32], IDC structure [19],[20] and CSRR[13]. The sensor has good performance with a maximum accuracy of 96% - 98% and a normalized sensitivity of 1.34% - 5.38%. However, the proposed sensor only supports transmission mode-based measurements and requires a two-port network analyzer for characterization, which can increase the complexity and cost of the measurement setup.

Previous studies introduced a single-port resonator incorporating a slot for permittivity detection of dielectric samples, achieving an accuracy of 98.80% and a normalized sensitivity of 5.24% [23]. However, the sensor's electric field remains inadequately localized and focused on the sensing area, potentially leading to measurement inaccuracies in the presence of interference or disturbances. In addition, the proposed sensor only operates at a single resonant frequency. Moreover, a single-port microwave sensor with dual band performance utilizing U-shaped [24] and T-shaped resonators [26] was proposed in another study, featuring independent characteristics for simultaneous detection of solid material permittivity and long-distance sensing. The electric field of the resonator was localized on its arm, designated as the sensing area. However, the study did not include an analysis of disturbance effects, leaving the stability of the proposed sensor under disturbed conditions unverified.

Previous work introduced a single-port microwave sensor employing aperture coupling [25] and an artificial magnetic conductor [21]. The electric field was localized on a separate substrate, designated as the sensor's sensing area. However, the proposed structure features a multilayer design, making it more complex to implement. Furthermore, the study did not include an analysis of disturbance effects, leaving the sensor's stability under such conditions unverified. This work provides an excellent solution to produce a microwave sensor using a single-port resonator that has high stability against disturbances. In this work, an interdigital capacitor structure is introduced to confine the E-field of the sensor to focus it on the sensing area of the sensor. In addition, the interdigital capacitor structure also reduces the H-field so that the E-field becomes more dominant. The stability of the sensor is evaluated and confirmed by placing a disturbance in the form of a rectangular copper shield placed directly above the sensor. The performance and stability of the sensor are observed in conditions without and with copper shielding for a distance range of d = 1 cm - 2.5 cm. From the measurement results, the sensor has high stability both without and with disturbance with a Frequency Detection Resolution (FDR) of 0.009 - 0.4 GHz/$\Delta\varepsilon_r$, a Normalized Sensitivity (NS) of 0.4% - 4.4%, and an average accuracy of 90% - 95% for both resonance frequencies, respectively.

Reference:

[1] K. S. L. Parvathi and S. R. Gupta, "Ultrahigh-Sensitivity and Compact EBG-Based Microwave Sensor for Liquid Characterization," *IEEE Sensors Lett.*, vol. 6, no. 4, pp. 19–22, 2022, doi: 10.1109/LSENS.2022.3159800.

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Decision letter (Revision 1)

IEEE Access - Decision on Manuscript ID Access-2025-00351

From: wsh.zhao@gmail.com
To: syah.alam@trisakti.ac.id, indra@trisakti.ac.id, lydia_sari@trisak.ac.id, deiny.wp@gmail.com, r.deiny@ui.ac.id, deiny_wp@trisakti.ac.id, teguhfirmansyah@untirta.ac.id, muh.iqbal@itb.ac.id, slamet_ae39@apps.ipb.ac.id, mudrikalaydrus@mercubuana.ac.id, zahriladha@utem.edu.my
CC: wsh.zhao@gmail.com

27-Jan-2025

Dear Dr. Alam:

Your manuscript entitled "High Stability Single-Port Dual Band Microwave Sensor Based on Interdigital Capacitor Structure with Asymmetry Branch Feedline" has been accepted for publication in IEEE *Access*. The comments of the reviewers who evaluated your manuscript are included at the foot of this letter. We ask that you make minor changes to your manuscript based on those comments, before uploading final files.

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Thank you for your fine contribution. On behalf of the Editors of IEEE *Access*, we look forward to your continued contributions to IEEE *Access*.

Sincerely,

Prof. Wen-Sheng Zhao
Associate Editor, IEEE *Access*
wsh.zhao@gmail.com

Reviewer(s)' Comments to Author:

Reviewer: 1

Comments:
N/A

Additional Questions:
Please confirm that you have reviewed all relevant files, including supplementary files and any author response files, which can be found in the "View Author's Response" link above (author responses will only appear for resubmissions): Yes, all files have been reviewed

1) Does the paper contribute to the body of knowledge?: Yes

2) Is the paper technically sound?: Yes

3) Is the subject matter presented in a comprehensive manner?: Yes

4) Are the references provided applicable and sufficient?: Yes

5) Are there references that are not appropriate for the topic being discussed?: Yes

5a) If yes, then please indicate which references should be removed.:

Reviewer: 2

Comments:
Dear author,
Your manuscript is know easily understood by the reader.
Good job.
Thank you

Additional Questions:
Please confirm that you have reviewed all relevant files, including supplementary files and any author response files, which can be found in the "View Author's Response" link above (author responses will only appear for resubmissions): Yes, all files have been reviewed

1) Does the paper contribute to the body of knowledge?: yes

2) Is the paper technically sound?: Yes

3) Is the subject matter presented in a comprehensive manner?: yes

4) Are the references provided applicable and sufficient?: yes

5) Are there references that are not appropriate for the topic being discussed?: No

5a) If yes, then please indicate which references should be removed.:

Reviewer: 3

Comments:
The paper proposes a single-port IDC based resonator for permittivity detection of solid materials with a permittivity range of 1 - 6.15. The microwave sensor is designed using a single-port resonator operating at two different resonant frequencies. The main comments are as follows:
1. As the dielectric constants of most solid materials are not frequency dependent, the reviewer wonder the necessity of proposing a dual-band sensor.
2. There will be air gap between the IDC surface and the solid materials. To the reviewer's knowledge, the air gap will have significant effect on the sensing results. How the authors can reduce this effect?
3. For further theoretical supporting, the reviewer would suggest the authors to refer to the IEEE T-MTT paper "Modeling of Coplanar Interdigital Capacitor for Microwave Microfluidic Application" for the relationship between IDC capacitance and the permittivity.

Additional Questions:
Please confirm that you have reviewed all relevant files, including supplementary files and any author response files, which can be found in the "View Author's Response" link above (author responses will only appear for resubmissions): Yes, all files have been reviewed

1) Does the paper contribute to the body of knowledge?: yes

2) Is the paper technically sound?: yes

3) Is the subject matter presented in a comprehensive manner?: yes

4) Are the references provided applicable and sufficient?: yes

5) Are there references that are not appropriate for the topic being discussed?: No

5a) If yes, then please indicate which references should be removed.:

If you have any questions, please contact article administrator: Mr. Ankit Srivastava
a.srivastava@ieee.org

Original Manuscript ID: *Access-2024-4890*

Original Article Title: *"High Stability Single-Port Dual Band Microwave Sensor Based on Interdigital Capacitor Structure with Asymmetry Branch Feedline"*

To:

Prof. Wen-Sheng Zhao

Associate Editor, IEEE Access

Re: Response to reviewers

Dear Editor,

Thank you for allowing the resubmission of our manuscript, with an opportunity to address the reviewers' comments.

We are uploading (a) our point-by-point response to the comments (below) (response to reviewers, under "Author's Response Files"), (b) an updated manuscript with yellow highlighting indicating changes (as "Highlighted PDF"), and (c) a clean updated manuscript without highlights ("Main Manuscript").

Best regards,

Syah Alam, et al.

Please address all correspondence to:

Syah Alam* / Zahriladha Zakaria**

*Department of Electrical Engineering, Universitas Trisakti, DKI Jakarta, 11440

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Corresponding author e-mail: *syah.alam@trisakti.ac.id / ** zahriladha@utem.edu.my

Reviewer# 1

Comments:

N/A

Additional Questions:

-

Response:

We thank the reviewer for constructive comments.

Reviewer# 2

Comments:

Dear author, your manuscript is known easily understood by the reader. Good job. Thank you

Response:

We thank the reviewer for constructive comments.

Reviewer#3:

The paper proposes a single-port IDC based resonator for permittivity detection of solid materials with a permittivity range of 1 - 6.15. The microwave sensor is designed using a single-port resonator operating at two different resonant frequencies. The main comments are as follows:

Concern # 1:

As the dielectric constants of most solid materials are not frequency dependent, the reviewer wonders the necessity of proposing a dual-band sensor.

Response:

We thank the reviewer for constructive comments. In this paper, the proposed sensor has dual band performance for permittivity detection of solid materials. This dual-band capability allows for more accurate and reliable characterization of materials, as different frequencies can penetrate varying depths or interact with material properties differently, providing a broader dataset for analysis. Furthermore, dual-band operation helps mitigate the effects of noise or interference from environmental factors, as measurements from both bands can be cross-referenced for consistency.

Author action:

We have added the advantages of the sensor with dual-band performance in the Section IV. VALIDATION WITH PREVIOUS WORK.

IV. VALIDATION WITH PREVIOUS WORKS

*A thorough evaluation comparing the proposed sensor's performance with previous studies is conducted, as detailed in **Table III**. A fair comparison with previous work is proposed by observing the performance of the sensor in terms of the method, permittivity range, resonance frequency (f_r), Frequency Detection Resolution (FDR), Normalized Sensitivity (NS) and accuracy. In addition, other performances that are compared are dual band characteristics, e-field localization, disturbance effect analysis and also high stability of the proposed sensor.*

Previous work proposed a microwave sensor using a dual-port resonator for permittivity detection of solid materials based on SRR [8],[10],[32], IDC structure [19],[20] and CSRR[13]. The sensor has good performance with a maximum accuracy of 96% - 98% and a normalized sensitivity of 1.34% - 5.38%. However, the proposed sensor only supports transmission mode-based measurements and requires a two-port network analyzer for characterization, which can increase the complexity and cost of the measurement setup.

Previous studies introduced a single-port resonator incorporating a slot for permittivity detection of dielectric samples, achieving an accuracy of 98.80% and a normalized sensitivity of 5.24% [23]. However, the sensor's electric field remains inadequately localized and focused on the sensing area, potentially leading to measurement inaccuracies in the presence of interference or disturbances. In addition, the proposed sensor only operates at a single resonant frequency. Moreover, a single-port microwave sensor with dual band performance utilizing U-shaped [24] and T-shaped resonators [26] was proposed in another study, featuring independent characteristics for simultaneous detection of solid material permittivity and long-distance sensing. The electric field of the *resonator was localized on its arm, designated as the sensing area. However, the study did not include an analysis of disturbance effects, leaving the stability of the proposed sensor under disturbed conditions unverified.*

Previous work introduced a single-port microwave sensor employing aperture coupling [25] and an artificial magnetic conductor [21]. The electric field was localized on a separate substrate, designated as the sensor's sensing area. However, the proposed structure features a multilayer design, making it more complex to implement. Furthermore, the study did not include an analysis of disturbance effects, leaving the sensor's stability under such conditions unverified. This work provides an excellent solution to produce a microwave sensor using a single-port resonator that has high stability against disturbances. In this work, an interdigital capacitor structure is introduced to confine the E-field of the sensor to focus it on the sensing area of the sensor. In addition, the interdigital capacitor structure also reduces the H-field so that the E-field becomes more dominant. The stability of the sensor is evaluated and confirmed by placing a disturbance in the form of a rectangular copper shield placed directly above the sensor. The performance and stability of the sensor are observed in conditions without and with copper shielding for a distance range of d = 1 cm - 2.5 cm. From the measurement results, the sensor has high stability both without and with disturbance with a Frequency Detection Resolution (FDR) of 0.009 - 0.4 GHz/$\Delta\varepsilon_r$, a Normalized Sensitivity (NS) of 0.4% - 4.4%, and an average accuracy of 90% - 95% for both resonance frequencies, respectively. ***Moreover, the proposed sensor has dual band performance with f_{r1} = 1.62 GHz and f_{r2}= 2.52 GHz. This dual-band capability allows for more accurate and reliable characterization of materials, as different frequencies can penetrate varying depths or interact with material properties differently, providing a broader dataset for analysis. Furthermore, dual-band operation helps mitigate the effects of noise or interference from environmental factors, as measurements from both bands can be cross-referenced for consistency.***

Concern # 2:

There will be air gap between the IDC surface and the solid materials. To the reviewer's knowledge, the air gap will have significant effect on the sensing results. How can the authors reduce this effect?

Response:

We thank the reviewer for constructive comments. In this paper, the sample used is a solid material with dimensions of 12.7 mm x 25 mm and a thickness of 1.6 mm. The sample is placed directly on the surface of the sensing area of the proposed sensor. We agree with the reviewer's comment that the air gap will affect the performance of the sensor. Therefore, we carefully ensure that the sensor is attached directly to the surface of the sensing area of the sensor. In addition, the dimensions of the sample and the sensing area are the same so that the sample is placed accurately.

Author action:

We have added the explanation about regarding the placement of samples on the proposed sensor in the Section III. MEASUREMENT RESULT AND VERIFICATION, sub-section A. MEASUREMENT OF PROPOSED SENSOR

A. MEASUREMENT OF PROPOSED SENSOR

The next stage is to validate the performance of the proposed sensor to characterize solid materials. In this work, the samples used are solid materials whose permittivity has been known based on the datasheet with a range of 1 - 6.15. ***Solid materials used as samples include RO5880 with a permittivity of 2.2, RO4003C with a permittivity of 3.65, FR4 with a permittivity of 4.3 and RO3006 with a permittivity of 6.15. The dimensions of the samples used are adjusted to the location of the sensing area of the proposed sensor, which is 12.7 mm x 25 mm with a sample thickness of 1.6 mm. The measurement scenario and placement of solid samples on the proposed sensor are shown in Fig. 8. In this work, the solid sample with dimensions of 10.7 mm x 23 mm x 1.6 mm is placed carefully on the sensing area surface protected by a rectangular copper shield with dimensions of 50 x 50 mm x 1.58 mm.*** *The copper shield is placed using a brass spacer placed at a certain distance represented by d. It should be noted that the copper shield is proposed as disturbance and also focuses on the electric field so that it is fully concentrated on the sample.*

Concern # 3:

For further theoretical supporting, the reviewer would suggest the authors to refer to the IEEE T-MTT paper "Modelling of Coplanar Interdigital Capacitor for Microwave Microfluidic Application" for the relationship between IDC capacitance and the permittivity.

Response:

We thank the reviewer for constructive comments. We have included the following references in the introduction.

Author action:

I. INTRODUCTION

Microwave sensors (MS) have seen significant advancement in the evaluation of both solids and liquids due to their advantages, such as high precision, a high Q-factor, cost-effectiveness, and compactness [1]–[3]. One of the measurable properties using MS is permittivity, which reflects a material's ability to sustain an electric field. The permittivity of the material under test (MUT) can be determined via perturbation theory, assuming the MUT behaves as a capacitive load [4]–[6]. ***Several microwave sensors based on resonators like the Split Ring Resonator (SRR) [7]–[10], Complementary Split Ring Resonator (CSRR)[11]–[13], Substrate Integrated Waveguide (SIW) [14],[15], Interdigital Capacitor (IDC) [16]–[21], AMC [22],[23] have been developed for solid and liquid material assessment.***

Previous work presented a single-port MS based on slot loaded [24] and dual U-shaped [25] for solid material characterization. Furthermore, another work proposed a dual-function permittivity sensor with an antenna using a single-port resonator for solid material characterization using an aperture coupling structure [26]. In addition, previous work [27] proposed a single-port microwave sensor based on dual T-shaped for contact and long-distance detection. The advantage of a single-port resonator-based microwave sensor is that it can also function as an antenna for data transmission[28]. However, the performance of a single-port resonator-based microwave sensor has a high potential to be inferred by electromagnetic waves and is also susceptible to disturbance. This is because the single-port resonator also transmits electromagnetic waves so that it is more susceptible to environmental disturbances, for example conducting materials. In addition, another limitation is that there is a higher likelihood of interference between the input and reflected signals. This can lead to difficulties and instability in the accuracy of representing measurement data. Therefore, a single-port resonator-based microwave sensor with high stability is needed to obtain accurate and reliable measurement results.

This work provides an excellent solution by proposing a high stability single-port MS based on Interdigital Capacitor (IDC) structure. The MS is designed to operate at two different frequencies f_{r1} = 1.61 GHz and f_{r2} = 2.52 GHz using an asymmetric branch feed line while the IDC structure is used to confine the concentration of the E-field in the sensing area so that the sensor is more focused on detecting samples. Furthermore, to observe the performance stability of the proposed sensor, a rectangular copper shield as conducting material is placed right above the sensor surface with a distance range of d = 1 cm - 2.5 cm to emulate as a disturbance. The performance of the sensor observed in this work is related to frequency shift, ΔF, Frequency Detection Resolution

(FDR), Normalized Sensitivity (NS) and average accuracy. In addition, an interdigital capacitor structure also can minimize the H-field distribution so that the highest E-field concentration is focused on the sensing area of the proposed sensor. From the measurement results, the proposed sensor has high stability both without and with disturbance for a distance range of d = 1 - 2.5 cm. The sensor has stable performance with a frequency detection resolution of 0.009 - 0.4 GHz/$\Delta\varepsilon_r$, a normalized sensitivity of 0.4% - 4.4%, and an average accuracy of 90% - 95% for both resonance frequencies, respectively.

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