Teguh Firmansyah <teguhfirmansyah@untirta.ac.id>

# AEUE-D-23-00484 - Confirming your submission to AEUE - International Journal of Electronics and Communications

1 pesan

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Modeling of Quasi-tapered Microstrip Antenna Based on Expansion-exponential Tapered Method and Its Application for Wideband MIMO Structure

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Teguh Firmansyah <teguhfirmansyah@untirta.ac.id>

# Confirming handling editor for submission to AEUE - International Journal of Electronics and Communications

1 pesan

**AEUE - International Journal of Electronics and Communications** <em@editorialmanager.com> 8 Maret 2023 pukul 06.03
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Kepada: Teguh Firmansyah <teguhfirmansyah@untirta.ac.id>

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Manuscript Number: AEUE-D-23-00484

Modeling of Quasi-tapered Microstrip Antenna Based on Expansion-exponential Tapered Method and Its Application for Wideband MIMO Structure

Dear Mr Firmansyah,

The above referenced manuscript will be handled by Editor-in-Chief Professor Shahram MINAEI.

To track the status of your manuscript, please log into Editorial Manager at https://www.editorialmanager.com/aeue/.

Thank you for submitting your work to this journal.

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Teguh Firmansyah <teguhfirmansyah@untirta.ac.id>

# Decision on submission to AEUE - International Journal of Electronics and Communications

4 pesan

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Balas Ke: AEUE - International Journal of Electronics and Communications <support@elsevier.com>
Kepada: Teguh Firmansyah <teguhfirmansyah@untirta.ac.id>

CC: andrea.morabito@unirc.it, sima_noghanian@ieee.org

Manuscript Number: AEUE-D-23-00484

Modeling of Quasi-tapered Microstrip Antenna Based on Expansion-exponential Tapered Method and Its Application for Wideband MIMO Structure

Dear Mr Firmansyah,

Thank you for submitting your manuscript to AEUE - International Journal of Electronics and Communications.

I have completed my evaluation of your manuscript. The reviewers recommend reconsideration of your manuscript following major revision. I invite you to resubmit your manuscript after addressing the comments below. Please resubmit your revised manuscript by May 05, 2023.

When revising your manuscript, please consider all issues mentioned in the reviewers' comments carefully: please outline every change made in response to their comments and provide suitable rebuttals for any comments not addressed. Please note that your revised submission may need to be re-reviewed.

To submit your revised manuscript, please log in as an author at https://www.editorialmanager.com/aeue/, and navigate to the "Submissions Needing Revision" folder.

AEUE - International Journal of Electronics and Communications values your contribution and I look forward to receiving your revised manuscript.

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Kind regards,
Shahram MINAEI
Editor-in-Chief

AEUE - International Journal of Electronics and Communications

Editor and Reviewer comments:

Reviewer #1:
1. A super wideband 2-port MIMO antenna is presented with the detailed analysis of the chosen tapered antenna geometry. Apart from the detailed analysis, the antenna lacks novelty. Also there is a major concern for the measurements carried out as single SMA connector is not capable of measuring the response at lower as well higher bands. Sub-6 GHz and mmwave bands need separate connectors.
2. List the novel contribution clearly and justify the need for the proposed antenna through extensive literature review.
3. Please refer to the attached file for more comments.

Reviewer #2:
The article entitled "Modeling of Quasi-tapered Microstrip Antenna Based on Expansion-exponential Tapered Method and Its Application for Wideband MIMO Structure" has been thoroughly reviewed and the current form of manuscript did not find suitable due to following comments:
Comment to the Authors:
1. Authors did not describe how to utilize the "Expansion-exponential Tapered Method" with the suggested design because it is an well known approach. It is a suggestion for authors to compare the results with simulation of the proposed design with the used tapered method.
2. From the results given in Fig. 12 & 13, the proposed design is a wideband antenna but authors have selected some specific bands only. Why?
3. From the results given in Fig 15, why are the cross-pol values high?
4. Channel capacity analysis of the proposed design is missing.
5. Authors did not disclose the name of software exploited for the analysis.

Associate Editor:
- Please clarify if ECC is calculated using the radiation patterns.
- The cross polarization patterns should be added to Fig. 15.
- Table I should include some references that propose MIMO wideband antennas.

*****

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## Pesan terlalu besar

Pesan Anda tidak dapat dikirim ke **kondoh.jun@shizuoka.ac.jp** karena ukurannya melebihi batas. Coba kurangi ukuran pesan dan kirimkan kembali.

Tanggapan dari server jarak jauh adalah:

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**To:** May 16, 2023

Editor in Chief of AEU International Journal of Electronics and Communications

Prof. Dr. Shahram Minaei.

**Re:** Response to reviewers

Dear Professor,

I hope this email finds you well and healthy. First of all, we want to thank you for evaluating and allowing us an opportunity to address the reviewers' comments. We have carefully revised the manuscript, according to the reviewers' comments. We are uploading:

1) Cover Letter
2) Response to Reviewers
3) Conflict of Interest
4) Author Agreement
5) **Revised** manuscript (clean version)
6) **Revised** Manuscript with Marked changes (with **yellow highlights**)
7) Figures

Moreover, we also provide **additional data/figures** to enrich the paper's discussion. It can be seen in **Figs. 7(a-b), 15(a-j), 17(a-b), 18(a-c).** Moreover, Jun Kondoh was included as an author to enhance the explanation and grammar evaluation.

Once again, we thank you for your valuable time reviewing and evaluating our paper. Please do not hesitate to contact me if there are any questions.

Sincerely Yours,
Teguh Firmansyah

Email:
teguhfirmansyah@untirta.ac.id

**Journal** : AEU International Journal of Electronics and Communications.
**Manuscript ID** : AEUE-D-23-00484
**Title** : Modeling of Quasi-tapered Microstrip Antenna Based on Expansion-exponential Tapered Method and Its Application for Wideband MIMO Structure

# Response Letter

**Journal** : AEU International Journal of Electronics and Communications.
**Manuscript ID** : AEUE-D-23-00484
**Title** : Modeling of Quasi-tapered Microstrip Antenna Based on Expansion-exponential Tapered Method and Its Application for Wideband MIMO Structure

First of all, we would like to thank the reviewers for their in-depth and constructive reviews of our manuscript and the editor for his careful reading and suggestion to resubmit our manuscript. In this revised version of the manuscript, we did our best to address all comments raised by the reviewers. A detailed item-by-item responses to each of the reviewers' points are presented below.

## Responses to reviewer 1

***Concern # No. 1:***
*A super wideband 2-port MIMO antenna is presented with the detailed analysis of the chosen tapered antenna geometry. Apart from the detailed analysis, the antenna lacks novelty. Also there is a major concern for the measurements carried out as single SMA connector is not capable of measuring the response at lower as well higher bands. Sub-6 GHz and mmwave bands need separate connectors.*

**Author response:** Many thanks to the reviewer for this feedback. **Regarding the novelty**, the study presented in this paper made several contributions, which are listed as follows:

1. A wideband antenna based on a quasi-tapered structure using a circular shape is proposed. A quasi-tapered characteristic was obtained by integrating a circular-shaped patch antenna with an inverted omega ground plane as shown in **Fig 1(a).**
2. We also proposed an expansion-exponential tapered model to investigate the quasi-tapered structure based on a circular shape. This proposed model was utilized due to the limitation of the traditional linear, exponential, and Klopfenstein tapering methods. It is important to note that our circular tapered structure diverges from the conventional linear, exponential, or Klopfenstein shapes typically employed in tapering.
3. To obtain the mathematical model of for the circular shape tapered structure, we expand the the existing exponential shape tapered model. In detail, **Fig 1(b)** illustrates the proposed circular tapered structure which is divided into two halves circular shapes. It is seen that the physical dimension of the left-side of the half-circular shape is increasing. However, if we investigate the impedance characteristic, the impedance value is decreasing. Therefore, the left side structure

has a convergent behavior. Vice versa, the right side of the half-circular shape has a divergent characteristic.

4. The study employs the ABCD parameter based on the transmission line model to investigate the overall antenna structure. The proposed model was verified by the finite element method (FEM). Following the verification process, the proposed antenna was then applied to a MIMO structure. The fabrication of the antenna was carried out on a Rogers RT/Duroid 5880 substrate with εr = 2.2, thickness of h = 1.6 mm, and dielectric loss tan δ = 0.0009.
5. In addition, we also proposed a multislot EBG structure to reduce the mutual coupling parameter in the MIMO antenna system. As a result, the proposed MIMO antenna demonstrated wide bandwidth and excellent performance across various communication bands. The antenna is capable of operating in the S-band to mmW band, effectively covering a broad frequency range. This wide frequency coverage enabled the antenna to support multiple communication standards, including 4G (3.3 GHz), mid-band 5G (3.4-3.8 GHz), WLAN (5.8 GHz), and high-band 5G (24.5-26 GHz) concurrently.

**Table 1.** Provides an overview of the proposed research positioning.

**Table 1.** Research position

| Ref | Freq. (GHz) | Antenna structure | Proposed methods | Applications | | MIMO antenna | Mutual coupling reduction | Advantages |
|---|---|---|---|---|---|---|---|---|
| | | | | Narrow-band | Wide-band | | | |
| [26] | 2.50 | Microstrip slot dipole | Recursive convex optimization | Yes | - | - | - | The proposed model has the capability to make predictions for the near field. |
| [27] | 30.0 | Micro-coaxial collinear | Equivalent circuit modeling | Yes | - | - | - | The calculation model is capable of identifying the equivalent circuit. |
| [28] | 2.47 - 2.56 | Stacked Microstrip Ring | Cavity model | Yes | - | - | - | The proposed model can predict the near field. |
| [29] | 1.50 - 2.50 | Stepped-Impedance Slot Antenna | Stepped-Impedance Resonator | Yes | - | - | - | The proposed model is capable of predicting the dualband impedance characteristics. |
| [30] | 2.00 - 8.00 | CPW-fed slot antenna with monopole | Space-mapping with kriging surrogates | - | Yes | - | - | The proposed model has the ability to forecast the value of reflection coefficient. |
| [31] | 3.00 | Conventional dipole | Linear elements | - | Yes | - | - | The model can estimate the radiation pattern. |
| [32] | 2.51 - 6.55 | Linear tapered slot | Equivalent circuit model | - | Yes | - | - | The calculation model has the potential to determine the equivalent circuit. |
| [33] | 3.50 - 8.50 | Monopole UWB | Statistical analysis model | - | Yes | - | - | The proposed model can make predictions for the value of reflection coefficient. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [34] | 2.20 | Monopole | Equivalent circuit model | Yes | - | Yes | - | The network parameters can be utilized for the prediction of S-parameters performance. |
| [35] | 5.15 - 5.35 | Monopole | The effective length matrices | Yes | - | Yes | - | The effective length matrices demonstrate good agreement with the method of moments. |
| [36] | 5.20 | FIFA-monopole | Eigen-Analysis | Yes | - | Yes | - | The model can determine the radiation pattern. |
| [37] | 2.90 - 18.00 | Circular shaped monopole | N.R. | - | Yes | Yes | Yes | The proposed antenna exhibits wideband performance. |
| [38] | 3.00 – 30.0 | Monopole with slot | N.R. | - | Yes | Yes | Yes | The proposed antenna possesses good isolation. |
| [39] | 3.30 –8.50 | L-shaped branch | N.R. | - | Yes | Yes | Yes | The proposed antenna has wideband performance. |
| This paper | 3.30 - 26.0 | Quasi-tapered using circular shaped | Expansion-exponential tapered model | - | Yes | Yes | Yes | The proposed antenna design combines wideband performance, a simple impedance calculation model, and low mutual coupling in a MIMO configuration. |

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 90 - 137, and Table 1.

**Regarding the connector,**

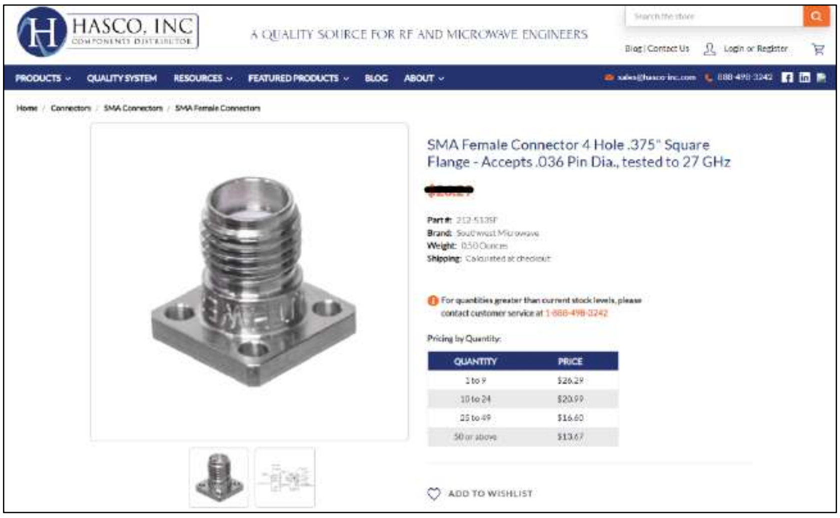
Many thanks to the reviewer for this feedback. It should be noted when measuring the antenna performance. We use two scenarios. The first scenario combines conventional-SMA (low-freq) and End-lunch (high-freq with modified feed line) connectors. Meanwhile, the second scenario measurement uses the latest generation of SMA connectors. This connector can work up to 27 GHz. The measurement results of both scenarios are the same.

For an additional answer, this is the link for our connector.

https://www.hasco-inc.com/connectors/sma-connectors/212-513sf-super-sma-jack-female-4-hole-375-square-flange-accepts-pin-dia-036/

and

https://www.hasco-inc.com/connectors/220-503sf-super-sma-jack-female-thread-in-accepts-pin-dia-036/





**Data sheet :**

ELECTRICAL

| Parameter | Specification |
|---|---|
| Frequency Range | DC - 27 GHz |
| VSWR | 1.15:1 Max |
| Impedance | 50 Ohms |

MATERIALS

| Item | Specification (Note: All plating thickness values are in micro-inches) |
|---|---|
| Body | Passivated Stainless Steel |
| Contact Pin | Beryllium Copper (BeCu), UNS C17300 Per ASTM B196, Gold Plated Per MIL-G-45204 or ASTM B488 |
| Center Contact Capture | High Temperature Ultem 1000 Per ASTM D5205 |
| Connector Interface | Per MIL-STD-348, Figs. 310-1 and 310-2 |

Based on the data sheet, it can be seen that the connector has a good performance at a high frequency of 27 GHz. Therefore, our measurements are solid, with the same results in both scenarios. Moreover, as the reviewer suggested, we added this information to the main manuscript with a yellow highlight.

**Author action:**
The measurement of the proposed antenna's performance up to 26 GHz was facilitated by using the first-generation of super SMA female connectors from HASCO. Based on the data sheet, this connector has good performance from DC up to 27 GHz [45]. Furthermore, an R&S ZVA67 VNA is used to measure the antenna performance.

**Reference :**

[45] L. Technologies, "SMA Connectors," *SMA Connectors*, 2012. [Online]. Available: https://www.hasco-inc.com/categories/connectors/sma-connectors.html.

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 378-381.

***Concern # No. 2:***
*List the novel contribution clearly and justify the need for the proposed antenna through extensive literature review.*

**Author response:** Thank you very much for the in-depth review. **Regarding the novelty**, the study presented in this paper made several contributions, which are listed as follows:

1. A wideband antenna based on a quasi-tapered structure using a circular shape is proposed. A quasi-tapered characteristic was obtained by integrating a circular-shaped patch antenna with an inverted omega ground plane as shown in **Fig 1(a).**
2. We also proposed an expansion-exponential tapered model to investigate the quasi-tapered structure based on a circular shape. This proposed model was utilized due to the limitation of the traditional linear, exponential, and Klopfenstein tapering methods. It is important to note that our circular tapered structure diverges from the conventional linear, exponential, or Klopfenstein shapes typically employed in tapering.
3. To obtain the mathematical model of for the circular shape tapered structure, we expand the the existing exponential shape tapered model. In detail, **Fig 1(b)** illustrates the proposed circular tapered structure which is divided into two halves circular shapes. It is seen that the physical dimension of the left-side of the half-circular shape is increasing. However, if we investigate the impedance characteristic, the impedance value is decreasing. Therefore, the left side structure has a convergent behavior. Vice versa, the right side of the half-circular shape has a divergent characteristic.
4. The study employs the ABCD parameter based on the transmission line model to investigate the overall antenna structure. The proposed model was verified by the finite element method (FEM). Following the verification process, the proposed antenna was then applied to a MIMO structure. The fabrication of the antenna was carried out on a Rogers RT/Duroid 5880 substrate with $\varepsilon r = 2.2$, thickness of $h = 1.6$ mm, and dielectric loss $\tan \delta = 0.0009$.

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**Table 1.** Research position

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| [27] | 30.0 | Micro-coaxial collinear | Equivalent circuit modeling | Yes | - | - | - | The calculation model is capable of identifying the equivalent circuit. |
| [28] | 2.47 - 2.56 | Stacked Microstrip Ring | Cavity model | Yes | - | - | - | The proposed model can predict the near field. |
| [29] | 1.50 - 2.50 | Stepped-Impedance Slot Antenna | Stepped-Impedance Resonator | Yes | - | - | - | The proposed model is capable of predicting the dualband impedance characteristics. |
| [30] | 2.00 - 8.00 | CPW-fed slot antenna with monopole | Space-mapping with kriging surrogates | - | Yes | - | - | The proposed model has the ability to forecast the value of reflection coefficient. |
| [31] | 3.00 | Conventional dipole | Linear elements | - | Yes | - | - | The model can estimate the radiation pattern. |
| [32] | 2.51 - 6.55 | Linear tapered slot | Equivalent circuit model | - | Yes | - | - | The calculation model has the potential to determine the equivalent circuit. |
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| [35] | 5.15 - 5.35 | Monopole | The effective length matrices | Yes | - | Yes | - | The effective length matrices demonstrate good agreement with the method of moments. |
| [36] | 5.20 | FIFA-monopole | Eigen-Analysis | Yes | - | Yes | - | The model can determine the radiation pattern. |
| [37] | 2.90 - 18.00 | Circular shaped monopole | N.R. | - | Yes | Yes | Yes | The proposed antenna exhibits wideband performance. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
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| This paper | 3.30 - 26.0 | Quasi-tapered using circular shaped | Expansion-exponential tapered model | - | Yes | Yes | Yes | The proposed antenna design combines wideband performance, a simple impedance calculation model, and low mutual coupling in a MIMO configuration. |

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 90 - 137, and Table 1.

***Concern # No. 3:***

**Please refer to the attached file for more comments : Reply for the commens from the attached file**

***Concern # No. 4:***

…………………… *to support the Society 5.0*?....

**Author response:** Many thanks to the reviewer for this comment. We have corrected the text as follows.

A massive communication network with high data-rate capability is required to support 5G technology [1], [2]. This challenging requirement has forced the development of 5G technology to work at the millimeter-wave (mmW) band to accommodate an enormous number of users with a wide bandwidth availability [3], [4]

**References :**


[1] B. Aghoutane, S. Das, M. EL Ghzaoui, B. T. P. Madhav, and H. El Faylali, “A novel dual band high gain 4-port millimeter wave MIMO antenna array for 28/37 GHz 5G applications,” *AEU - Int. J. Electron. Commun.*, vol. 145, no. December 2021, p. 154071, 2022, doi: 10.1016/j.aeue.2021.154071.

[2] B. Feng, Y. Tu, J. Chen, K. L. Chung, and S. Sun, “High-performance dual circularly-polarized antenna arrays using 3D printing for 5G millimetre-wave communications,” *AEU - Int. J. Electron. Commun.*, vol. 130, no. June 2020, p. 153569, 2021, doi: 10.1016/j.aeue.2020.153569.

[3] V. Yadav, R. S. Yadav, P. Yadav, B. Mishra, and A. Kumar, “Dual and wideband 6-port MIMO antenna for WiFi, LTE and carrier aggregation systems applications,” *AEU - Int. J. Electron. Commun.*, vol. 162, no. February, 2023, doi: 10.1016/j.aeue.2023.154576.

[4] K. Cuneray, N. Akcam, T. Okan, and G. O. Arican, “28/38 GHz dual-band MIMO antenna with wideband and high gain properties for 5G applications,” *AEU - Int. J. Electron. Commun.*, vol. 162, no. January, p. 154553, 2023, doi: 10.1016/j.aeue.2023.154553.

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 71-73.

***Concern # No. 5:***

*Authors should emphasize that feeding needs to be optimized for an antenna to work at both lower and higher band simultaneously. The same feedline width and the connector cant be used for lower as well higher operational bands. At lower bands SMA connector can suffice the purpose however as the frequency increases the feedline will become thinner so end launch connectors are needed,*

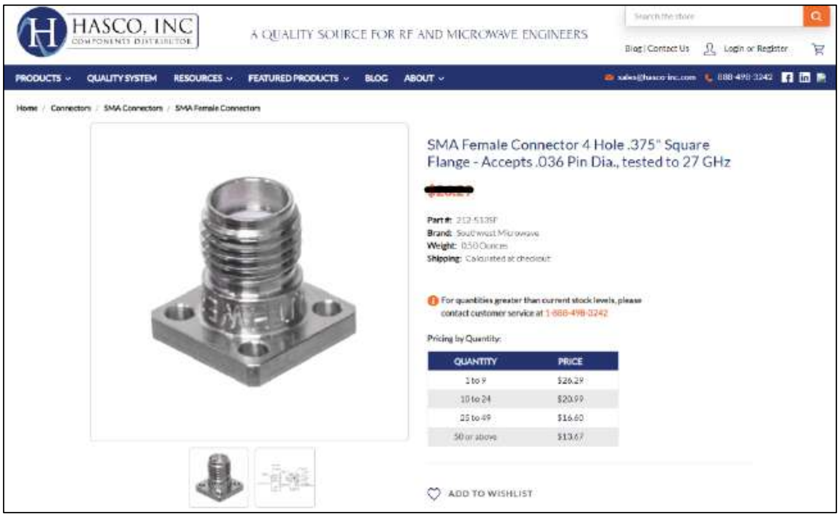
**Author response:** Many thanks to the reviewer for this feedback. It should be noted when measuring the antenna performance. We use two scenarios. The first scenario combines conventional-SMA (low-freq) and End-lunch (high-freq with modified feed line) connectors. Meanwhile, the second scenario measurement uses the latest generation of SMA connectors. This connector can work up to 27 GHz. The measurement results of both scenarios are the same.

For an additional answer, this is the link for our connector.

https://www.hasco-inc.com/connectors/sma-connectors/212-513sf-super-sma-jack-female-4-hole-375-square-flange-accepts-pin-dia-036/

and

https://www.hasco-inc.com/connectors/220-503sf-super-sma-jack-female-thread-in-accepts-pin-dia-036/




### Data sheet :

ELECTRICAL

| Parameter | Specification |
|---|---|
| Frequency Range | DC - 27 GHz |
| VSWR | 1.15:1 Max |
| Impedance | 50 Ohms |

MATERIALS

| Item | Specification (Note: All plating thickness values are in micro-inches) |
|---|---|
| Body | Passivated Stainless Steel |
| Contact Pin | Beryllium Copper (BeCu), UNS C17300 Per ASTM B196, Gold Plated Per MIL-G-45204 or ASTM B488 |
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**Author action:**

The measurement of the proposed antenna's performance up to 26 GHz was facilitated by using the first-generation of super SMA female connectors from HASCO. Based on the data sheet, this connector has good performance from DC up to 27 GHz [45]. Furthermore, an R&S ZVA67 VNA is used to measure the antenna performance.

**Reference :**

[45] L. Technologies, "SMA Connectors," *SMA Connectors*, 2012. [Online]. Available: https://www.hasco-inc.com/categories/connectors/sma-connectors.html.

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 378-381.

**Concern # No. 6:**

The proposed **of** half-circular shape tapered configuration with expansion-exponential tapered model is shown in **Fig. 2(a).**

**Author response:** Thank you for your correction. We have remove the "**of**" at the main manuscript. Then, the corrected text is shown in as follows.

The proposed half-circular shape tapered configuration with expansion-exponential tapered model is shown in Fig. 2(a).

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 156-157.

**Concern # No. 7:**

Please use different color for the lines. Also only keep three very relevant results (shown in **Fig. 8,** now **shown in Fig 9**).

**Author response:**

Thank you very much for your comment. We agree with the reviwer, we have revised Fig 8. now shown in Fig 9 as shown in below.

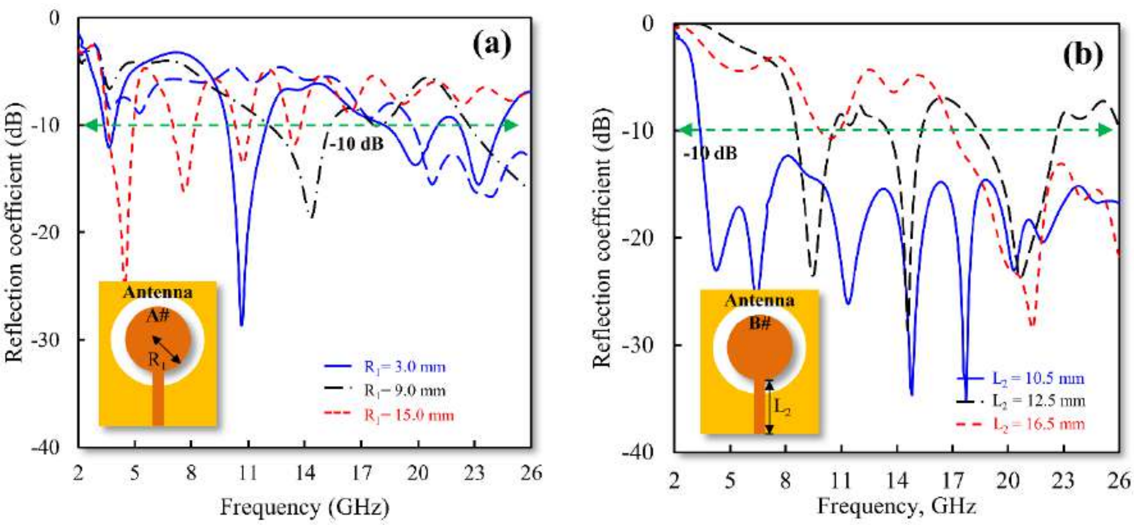


**Fig. 9.** (a) Reflection coefficient of antenna A# with varied of $R_1$, (b) Reflection coefficient of antenna B# with varied of $L_2$

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 321-322.

***Concern # No. 8:***

*No radiation pattern is shown here.* **(Fig 14.** now shown in **Fig 15)**

**Author response:**

Thank you very much for pointing this out. We appologize for our mistakes by mention a wrong caption. We have revised the radiation pattern as shown in **Fig 15.**

**Fig. 15 (a-j)** presents the normalized co-and cross-polarization radiation patterns of the proposed antenna. Specifically, **Fig. 15 (a-e)** display the normalized co- and cross-polarization radiation patterns at the XOZ-plane for frequencies of 3.3 GHz, 5.8 GHz, 10 GHz, 24 GHz, and 26 GHz, respectively. It is seen at the XOZ-plane, the cross-polarization values are relatively large. However, the main beam at 0 degree exhibits a very low cross-polarization value. Moreover, **Fig. 15 (a-e)** show the normalized co- and cross-polarization radiation patterns at YOZ-plane for frequencies of 3.3 GHz, 5.8 GHz, 10 GHz, 24 GHz, and 26 GHz, respectively. At the YOZ-plane direction, the proposed antenna exhibits a very low cross-polarization value. Therefore, it can be concluded the proposed antenna has omni-directional pattern at the YOZ-plane.

As an additional explanation, there are several reasons that the monopole antenna can generate circular polarization such as ground-plane's position and antenna shape [46]–[48]. The ground-plane plays an important role in determining the polarization of an antenna. In the specific case of a monopole antenna, the ground plane can cause the polarization of the signal to change from its original orientation, with a larger ground plane providing more reflection and resulting in a more significant change in polarization [46]–[48].

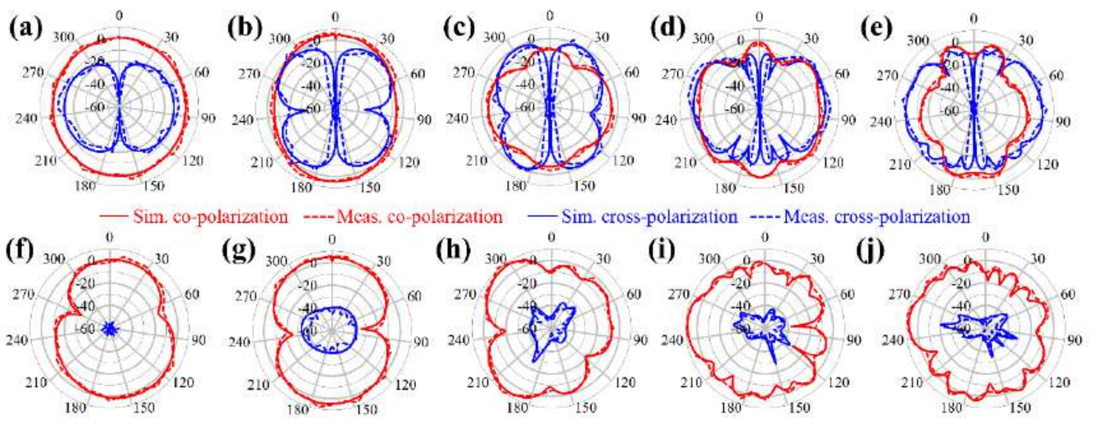


**Fig. 15.** Co- and cross-polarization normalized radiation patterns at XOZ-plane at frequency of (a) 3.3 GHz, (b) 5.8 GHz, (c) 10 GHz, (d) 24 GHz, and (e) 26 GHz. Then, Co- and cross-polarization normalized radiation patterns at YOZ-plane at frequency of (f) 3.3 GHz, (g) 5.8 GHz, (h) 10 GHz, (i) 24 GHz, and (j) 26 GHz.

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 406-426.

***Concern # No. 9:***

*Include simulated and measured gain and efficiency results of the antenna.*

**Author response:** Thank you very much for your comment. We agree with the reviewer. We have added the data as shown in **Fig 17 (a).** However, we appologize only give a simulation data for the efficiency. We hope this data do not reduce our main proposed content such as a modeling of quasi-tapered microstrip antenna based on expansion-exponential tapered method and its application for wideband MIMO structure.

A realized gain and efficiency of MIMO antenna C4# is shown in **Fig 17(a).** As depicted in the graph, the antenna has a realized gain ranging from 2.0 dBi to 9.5 dBi. The efficiency value range from 95.4% to 98.2 %. It is important to note that only simulation data for efficiency are presented due to the limitations of the measurement device. However, the obtained results indicate good performance in terms of efficiency. This is attributed due to the low loss of Rogers RT/Duroid 5880 substrate which has a dielectric loss tangent (tan δ) of 0.0009.

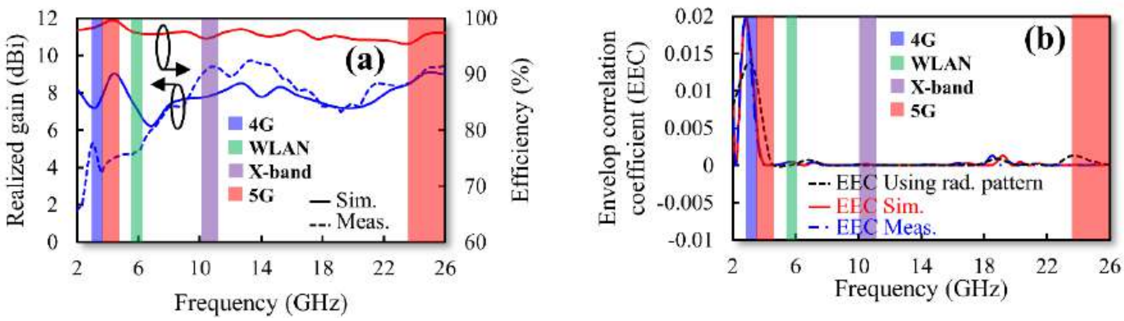


**Fig. 17.** Comparison result of (a) realized gain and efficiency, (b) enveloped correlation coefficient

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 441-452.

***Concern # No. 10:***

*Table 2. Include the size of the antennas in terms of lambda and the shape of radiation pattern.*

**Author response:**

Thank you very much for your comment. We agree with the reviewer. Therefore, we have revised **Table 2**, including the size of the antennas in terms of lambda and the shape of the radiation pattern. In detail, **Table 2** shows a performance comparison of the proposed antenna with published antennas. It can be seen that the proposed antenna has wide bandwidth with good MIMO performance. Moreover, it should be mentioned here we have re-measured our co- and cross-polarization data as shown in **Fig. 15.**

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 423-426.

**Table 2.** Performance comparison of the proposed antenna with published antennas

| Ref. | Antenna structure | $f_c$ / BW (GHz) | Proposed application | Size ($\lambda_0$) | Substrtae | Shape of rad. pattern | Port | Isolation (dB) | Realized Gain (dBi) | Efficiency (%) | CCL | EEC | DG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [51] | Quasi self complementary | 6.85/ 7.50 | WLAN, UWB | 0.73 × 0.73 | FR4, $\varepsilon_r$ = 4.4, h = 1.57, tan δ = 0.02 | Omni directional | 4 | < –15 | 1.7 – 4.2 | 60 - 90 | N.R | N.R | N.R |
| [52] | Planar-monopole | 7.40/ 9.20 | UWB | 0.64 × 0.76 | RTDuroid4350B, $\varepsilon_r$ = 3.5, h = 0.8, tan δ = 0.004 | Omni directional | 2 | < –20 | -2 – 5.8 | 95 - 99 | N.R | N.R | N.R |
| [53] | Koch fractal monopole | 7.5/ 9.0 | C-Band, UWB | 1.12 × 0.62 | FR4, $\varepsilon_r$ = 4.4, h = 1.57, tan δ = 0.02 | Omni directional | 2 | < –19 | 1.0 – 5.0 | N.R | N.R | 0.17 | N.R |
| [54] | Monopole with floating parasitic | 6.85/ 7.50 | UWB | 0.80 × 0.91 | RTDuroid4003, $\varepsilon_r$ = 4.3, h = 1.57, tan δ = 0.0024 | Omni directional | 2 | < –16 | 3.4 – 6.5 | N.R | N.R. | 0.2 | N.R |
| [55] | Single-dipole | 3.65/ 0.30 | 5G | 1.70 × 2.06 | FR4, $\varepsilon_r$ = 4.4, h = 1, tan δ = 0.02 | Directional | 2 | < –18 | N.R. | 80 -90 | N.R. | 0.1 | N.R. |
| [56] | Dual monopole | 7.55/ 8.90 | WLAN and 5G | 0.55 × 0.90 | RTDuroid5880, $\varepsilon_r$ = 2.2, h = 1.57, tan δ = 0.0009 | Omni directional | 2 | < –18 | N.R | N.R | N.R | 0.35 | N.R. |
| [57] | Monopole with EBG | 2.42/ 0.15 | WLAN | 0.23 × 0.30 | FR4, $\varepsilon_r$ = 4.4, h = 1, tan δ = 0.02 | Directional | 2 | < –24 | ~ 4.25 | 50 – 58 | N.R | 0.008 | 9.99 |
| [58] | Circular monopole | 2.50/ 0.60 | WLAN | 0.58 × 0.33 | JC, $\varepsilon_r$ = 1.6, h = 1, tan δ = 0.02 | Omni directional | 2 | < –16 | ~ 3.0 | N.R | N.R | 0.05 | N.R |
| [59] | CPW Asymmetric EBG | 4.75/ 2.90 | Sub-6 GHz 5G | 0.34 × 0.66 | FR4, $\varepsilon_r$ = 4.4, h = 1.57, tan δ = 0.02 | Omni directional | 2 | < -18 | N.R | N.R | N.R | 0.025 | ~ 10.0 |
| [60] | O-shaped monopole | 4.10/ 3.40 | WLAN and 5G | 0.13 × 0.62 | FR4, $\varepsilon_r$ = 4.4, h = 1.57, tan δ = 0.02 | Omni directional | 2 | < –23 | 2 – 4 | 20.0 - 65.0 | N.R | N.R | N.R |
| [61] | Octagonal-elips shaped | 11.0/ 18.0 | UWB and 5G | 1.46 × 1.61 | FR4, $\varepsilon_r$ = 4.4, h = 1.57, tan δ = 0.02 | Omni directional | 2 | < –15 | ~ 10.0 | 90 -92 | N.R | 0.02 | 9.80 - 10.00 |
| [62] | Octagonal-shaped radiating | 6.85/ 7.50 | UWB with noch | 0.43 × 0.68 | FR4, $\varepsilon_r$ = 4.4, h = 1.57, tan δ = 0.02 | Omni directional | 2 | < -18 | 1.2 – 2.91 | 70 - 90 | <0.05 | <0.02 | 9.40 - 10.00 |
| [63] | Metamaterial and SIW | 9.00/ 14.00 | UWB | 1.05 × 1.08 | FR4, $\varepsilon_r$ = 4.4, h = 1.57, tan δ = 0.02 | Omni directional | 2 | < –23 | 3.7 – 4.3 | 65 -80 | <0.04 | 0.04 | 1.5-10 |
| This paper | Quasi-tapered using circular shaped | 14.65/ 22.70 | 4G / Mid-band 5G / WLAN /X-Band / High band 5G | 4.15 × 2.09 | RTDuroid5880, $\varepsilon_r$ = 2.2, h = 1.57, tan δ = 0.0009 | Omni directional | 2 | < -20 | 2.0 - 9.5 | 95.4 – 98.2 | <0.04 | <0.02 | 9.88 - 10 |

Note : fc = frequency center, BW = bandwidth, CCL = channel capacity loss, EEC = envelop correlation coefficient, DG = diversity gain, and N.R = not reported.

## Responses to reviewer 2

***Concern # No. 1:***

*Authors did not describe how to utilize the "Expansion-exponential Tapered Method" with the suggested design because it is an well known approach. It is a suggestion for authors to compare the results with simulation of the proposed design with the used tapered method.*

**Author response:** Many thanks to the reviewer for this fruitful feedback and insightful suggestion. We have added the comparison between the proposed expansion-exponential tapered and conventional tapered methods of circular convergent-taper and circular divergent-taper, as shown in **Fig 7(a) and 7(b),** respectively.

**Fig. 7(a) and 7(b)** show the results comparison between the expansion-exponential tapered method and conventional tapered method for circular convergent-taper and circular divergent-taper configurations, respectively. MATLAB software was used to perform the calculations for both the expansion-exponential and conventional tapered methods. In addition to MATLAB, the transmission line electromagnetics modeling tool suite of TNT 1.2.2 was utilized for the FEM based calculations. It is observed that the proposed method exhibited greater consistency and better fit with the FEM results. These results look similar for circular-convergent taper and circular-divergent taper. However, if we compare it with the conventional tapered methods, the deviation is significant. This results suggests that the proposed expansion-exponential tapered method offers distinct advantages and a more suitable design approach compared to conventional methods. Additionally, it is important to note that further detailed investigations of the antenna characteristics were conducted using CST Microwave Studio software.

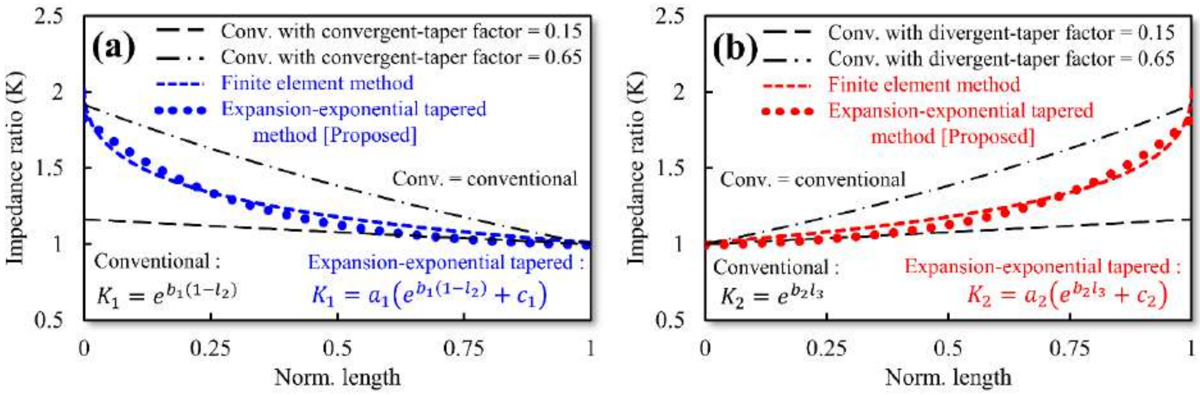


**Fig. 7.** Results comparison between the proposed method expansion-exponential tapered method and conventional tapered method (a) circular convergent-taper, and (b) circular divergent-taper.

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 282-298.

***Concern # No. 2:***

*From the results given in Fig. 12 & 13, the proposed design is a wideband antenna but authors have selected some specific bands only. Why?.*

**Author response:** Thank you very much for your comment.

It should be noted that, in principle, this antenna has the potential to operate across wide frequency bands. However, in this paper, the focus was directed towards specific frequency bands in order to position the study within the context of future communication technologies. We have selected several specific bands such as the 4G (3.3 ghz), mid-band 5G (3.4-3.8 ghz), WLAN (5.8 ghz), X-band (10-11 ghz), and high-band 5G (24.5-26 ghz) communications.

Moreover, this paper is also focused on development and modeling of quasi-tapered microstrip antenna based on expansion-exponential tapered method and its application for wideband MIMO structure.

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 400-405.

***Concern # No. 3:***

*From the results given in Fig 15, why are the cross-pol values high?*

**Author response:** Thank you very much for your comment. We have re-evaluated our data regarding the radiation patterns. Therefore, we have re-measured of our co- and cross-polarization data. It can be clearly seen at **Fig. 15.**

**Fig. 15 (a-j)** presents the normalized co-and cross-polarization radiation patterns of the proposed antenna. Specifically, **Fig. 15 (a-e)** display the normalized co- and cross-polarization radiation patterns at the XOZ-plane for frequencies of 3.3 GHz, 5.8 GHz, 10 GHz, 24 GHz, and 26 GHz, respectively. It is seen at the XOZ-plane, the cross-polarization values are relatively large. However, the main beam at 0 degree exhibits a very low cross-polarization value. Moreover, **Fig. 15 (a-e)** show the normalized co- and cross-polarization radiation patterns at YOZ-plane for frequencies of 3.3 GHz, 5.8 GHz, 10 GHz, 24 GHz, and 26 GHz, respectively. At the YOZ-plane direction, the proposed antenna exhibits a very low cross-polarization value. Therefore, it can be concluded the proposed antenna has omni-directional pattern at the YOZ-plane.

As an additional explanation, there are several reasons that the monopole antenna can generate circular polarization such as ground-plane's position and antenna shape [46]–[48]. The ground-plane plays an important role in determining the polarization of an antenna. In the specific case of a monopole antenna, the ground plane can cause the polarization of the signal to change from its original orientation, with a larger ground plane providing more reflection and resulting in a more significant change in polarization [46]–[48].

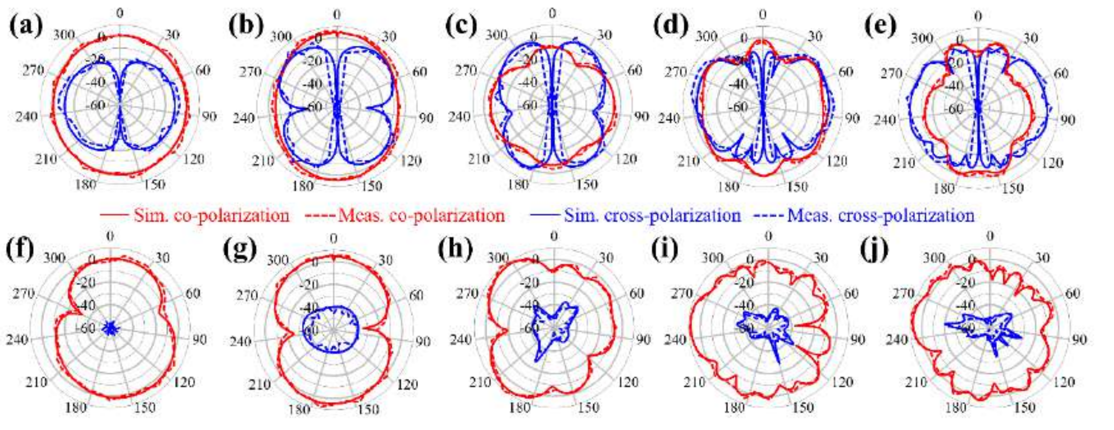

**Fig. 15.** Co- and cross-polarization normalized radiation patterns at XOZ-plane at frequency of (a) 3.3 GHz, (b) 5.8 GHz, (c) 10 GHz, (d) 24 GHz, and (e) 26 GHz. Then, Co- and cross-polarization normalized radiation patterns

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 406-426.

***Concern # No. 4:***

*Channel capacity analysis of the proposed design is missing.*

**Author response:** Thank you very much for the in-depth review. As a reviewer suggested, we have added the channel capacity analysis as shwon in **Fig 18 (c)**

**Fig. 18(a-c)** show comparison result of diversity gain (DG), total active reflection coefficient (TARC), and channel capacity loss (CCL) of the MIMO antenna C4#, respectively. Moreover, we can also calculate the DG value using the EEC obtained from the radiation patterns. The DG maximum value achieved is 10 dB, while the proposed MIMO antenna C4# has a high DG of above 9.9 dB. This means the proposed antenna performs well in terms of MIMO performance. Additionally, the TARC value which is a metric to relates the reflection power an N-port microwave component can be calculated using equations from [4], [49], [50]. The TARC value of the proposed antenna is lower than -10 dB which indicates that the reflection power is very low. Then, the CCL value is lower than 0.4, which is suitable for MIMO applications. **Table 2** shows the comparison between our proposed design and previous published antennas. The result shows that the proposed structure has many advantages that are suitable for 5G applications.

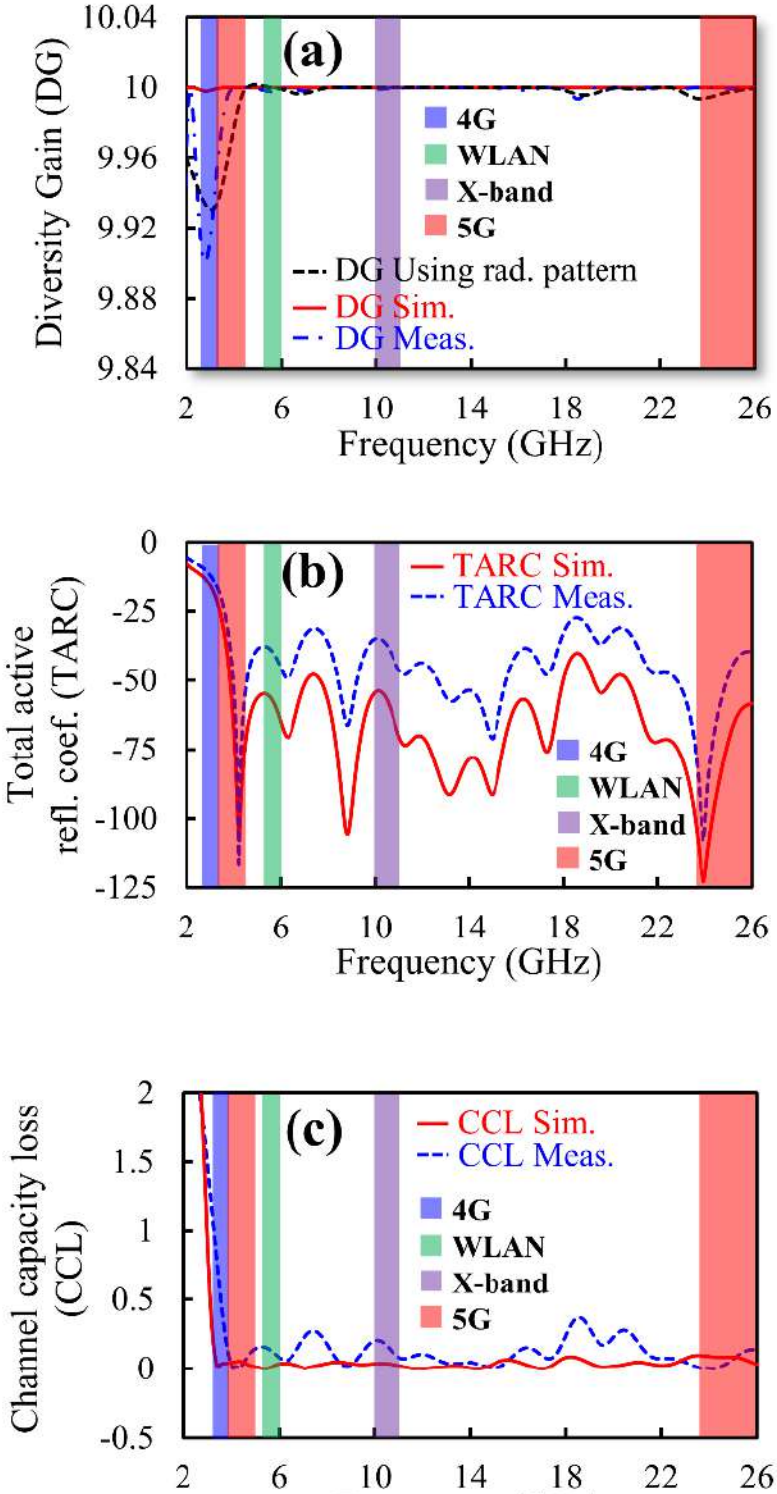


**Fig. 18.** Comparison result of (a) diversity gain, (b) total active reflection coefficient, and (c) channel capacity loss

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 456-469.

***Concern # No. 5:***
*Authors did not disclose the name of software exploited for the analysis.*

**Author response:** Thank you very much for your comment. We agree with this suggestion.

MATLAB software was used to perform the calculations for both the expansion-exponential and conventional tapered methods. In addition to MATLAB, the transmission line electromagnetics modeling tool suite of TNT 1.2.2 was utilized for the FEM based calculations. It is observed that the proposed method exhibited greater consistency and better fit with the FEM results. These results look similar for circular-convergent taper and circular-divergent taper. However, if we compare it with the conventional tapered methods, the deviation is significant. This results suggests that the proposed expansion-exponential tapered method offers distinct advantages and a more suitable design approach compared to conventional methods. Additionally, it is important to note that further detailed investigations of the antenna characteristics were conducted using CST Microwave Studio software.

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 285-293.

## Responses to Associate Editor

***Concern # No. 1:***

*Please clarify if ECC is calculated using the radiation patterns.*

**Author response:** Many thanks to the reviewer for this fruitful feedback. We agree with the comments. We have added the EEC data by calculating the radiation patterns. It can be seen in **Fig 17 (b).**

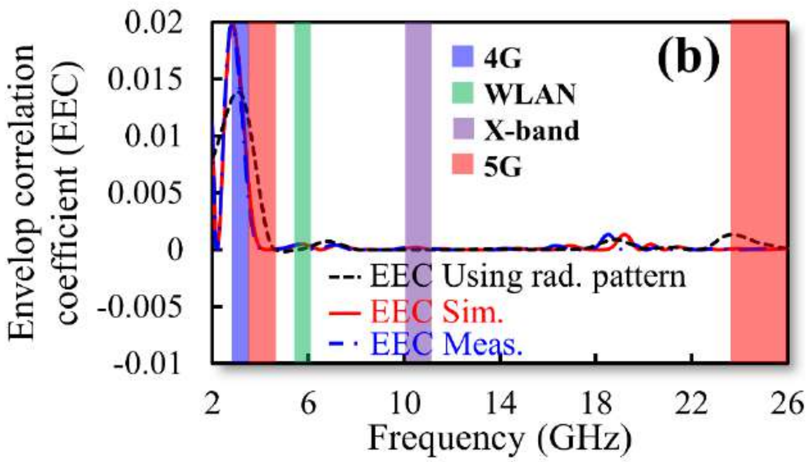


**Fig. 17 (b).** Comparison result of (b) enveloped correlation coefficient

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 452-455.

***Concern # No. 2:***

*The cross polarization patterns should be added to Fig. 15*

**Author response:** Thank you very much for your comment. We have re-evaluated our data regarding the radiation patterns. Therefore, we have re-measured of our co- and cross-polarization data. It can be clearly seen at **Fig. 15.**

**Fig. 15 (a-j)** presents the normalized co-and cross-polarization radiation patterns of the proposed antenna. Specifically, **Fig. 15 (a-e)** display the normalized co- and cross-polarization radiation patterns at the XOZ-plane for frequencies of 3.3 GHz, 5.8 GHz, 10 GHz, 24 GHz, and 26 GHz, respectively. It is seen at the XOZ-plane, the cross-polarization values are relatively large. However, the main beam at 0 degree exhibits a very low cross-polarization value. Moreover, **Fig. 15 (a-e)** show the normalized co- and cross-polarization radiation patterns at YOZ-plane for frequencies of 3.3 GHz, 5.8 GHz, 10 GHz, 24 GHz, and 26 GHz, respectively. At the YOZ-plane direction, the proposed antenna exhibits a very low cross-polarization value. Therefore, it can be concluded the proposed antenna has omni-directional pattern at the YOZ-plane.

As an additional explanation, there are several reasons that the monopole antenna can generate circular polarization such as ground-plane's position and antenna shape [46]–[48]. The ground-plane plays an important role in determining the polarization of an antenna. In the specific case of a monopole antenna, the ground plane can cause the polarization of the signal to change from its original orientation, with a larger ground plane providing more reflection and resulting in a more significant change in polarization [46]–[48].

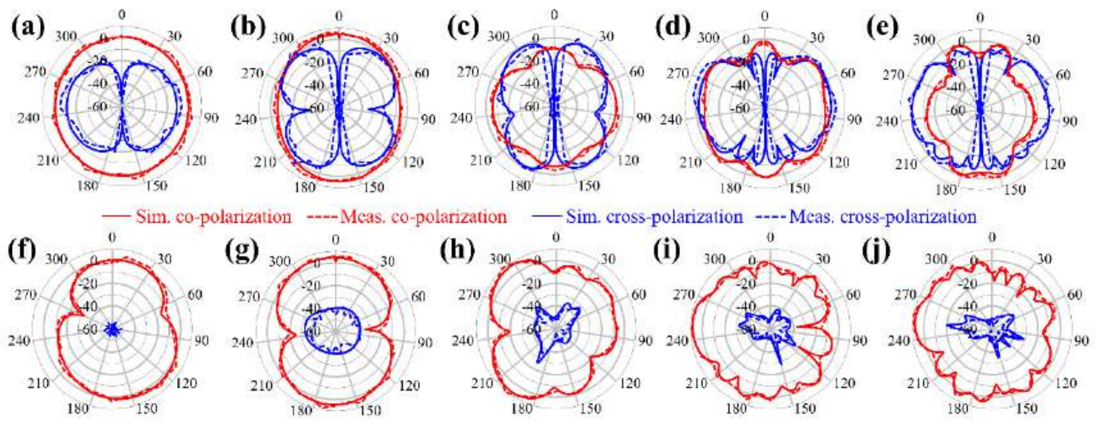


**Fig. 15.** Co- and cross-polarization normalized radiation patterns at XOZ-plane at frequency of (a) 3.3 GHz, (b) 5.8 GHz, (c) 10 GHz, (d) 24 GHz, and (e) 26 GHz. Then, Co- and cross-polarization normalized radiation patterns

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 406-426.

***Concern # No. 3:***

*Table I should include some references that propose MIMO wideband antennas.*

**Author response:** Thank you very much for your comment. We agree with this suggestion. We have added some references that propose MIMO wideband antennas. **Table 1** provides an overview of the proposed research positioning.

**Table 1.** Research position

| Ref | Freq. (GHz) | Antenna structure | Proposed methods | Applications | | MIMO antenna | Mutual coupling reduction | Advantages |
|---|---|---|---|---|---|---|---|---|
| | | | | Narrow-band | Wide-band | | | |
| [26] | 2.50 | Microstrip slot dipole | Recursive convex optimization | Yes | - | - | - | The proposed model has the capability to make predictions for the near field. |
| [27] | 30.0 | Micro-coaxial collinear | Equivalent circuit modeling | Yes | - | - | - | The calculation model is capable of identifying the equivalent circuit. |
| [28] | 2.47 - 2.56 | Stacked Microstrip Ring | Cavity model | Yes | - | - | - | The proposed model can predict the near field. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| [29] | 1.50 - 2.50 | Stepped-Impedance Slot Antenna | Stepped-Impedance Resonator | Yes | - | - | - | The proposed model is capable of predicting the dualband impedance characteristics. |
| [30] | 2.00 - 8.00 | CPW-fed slot antenna with monopole | Space-mapping with kriging surrogates | - | Yes | - | - | The proposed model has the ability to forecast the value of reflection coefficient. |
| [31] | 3.00 | Conventional dipole | Linear elements | - | Yes | - | - | The model can estimate the radiation pattern. |
| [32] | 2.51 - 6.55 | Linear tapered slot | Equivalent circuit model | - | Yes | - | - | The calculation model has the potential to determine the equivalent circuit. |
| [33] | 3.50 - 8.50 | Monopole UWB | Statistical analysis model | - | Yes | - | - | The proposed model can make predictions for the value of reflection coefficient. |
| [34] | 2.20 | Monopole | Equivalent circuit model | Yes | - | Yes | - | The network parameters can be utilized for the prediction of S-parameters performance. |
| [35] | 5.15 - 5.35 | Monopole | The effective length matrices | Yes | - | Yes | - | The effective length matrices demonstrate good agreement with the method of moments. |
| [36] | 5.20 | FIFA-monopole | Eigen-Analysis | Yes | - | Yes | - | The model can determine the radiation pattern. |
| [37] | 2.90 - 18.00 | Circular shaped monopole | N.R. | - | Yes | Yes | Yes | The proposed antenna exhibits wideband performance. |
| [38] | 3.00 – 30.0 | Monopole with slot | N.R. | - | Yes | Yes | Yes | The proposed antenna possesses good isolation. |
| [39] | 3.30 –8.50 | L-shaped branch | N.R. | - | Yes | Yes | Yes | The proposed antenna has wideband performance. |
| This paper | 3.30 - 26.0 | Quasi-tapered using circular shaped | Expansion-exponential tapered model | - | Yes | Yes | Yes | The proposed antenna design combines wideband performance, a simple impedance calculation model, and low mutual coupling in a MIMO configuration. |

**Author action:** We updated the manuscript by the yellow highlighted as shown on lines 90 - 137, and Table 1.

Again, we thank you for the valuable time you put into reviewing and evaluating our paper. Finally, please do not hesitate to contact me if there are any questions.

Yours Sincerely,

Teguh Firmansyah
**Email:**
teguhfirmansyah@untirta.ac.id

Teguh Firmansyah <teguhfirmansyah@untirta.ac.id>

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Shahram MINAEI
Editor-in-Chief

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Editor and Reviewer comments:

Area Editor:
All reviewers' comments have been addressed. The revised manuscript can now be accepted.

Reviewer #1:
The comments are well addressed and implemented.

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