A Modified Compact 2.4 GHz L-Shaped Microstrip Patch Antenna with Gain Enhancement for ISM-Band Internet of Things (IoT) Applications

1. Submitted to the journal "**electronics**" (23-3-2023)
2. First revision: Major revision (7-4-2023)
3. The author's request for a postponement of time due to the many revisions (13-4-2023)
4. Revised version submitted (26-4-2023)
   - Revisions Report and Amends
5. Second revision: Major revisions (1-5-2023)
6. Revised version submitted (2-5-2023)
   - Revisions Report and Amends
7. Paper accepted for publication (3-5-2023)
   - Reviewer comment with acceptance
   - Certificate
8. Proofread document received (4-5-2023)
   - Document from proofreading service
9. Revised proofread document has been submitted (5-5-2023)
10. Paper published (8-5-2023)
    - Certificate
    - Banner
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1. Submitted to the journal "**electronics**" (23-3-2023)

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[Electronics] Manuscript ID: electronics-2330743 - Submission Received

1 message

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Dear Dr. Fitra,

Thank you very much for uploading the following manuscript to the MDPI submission system. One of our editors will be in touch with you soon.

Journal name: Electronics
Manuscript ID: electronics-2330743
Type of manuscript: Article
Title: A Modified Compact 2.4 GHz L-Shaped Microstrip Patch Antenna with Gain Enhancement for ISM-Band Internet of Things (IoT) Applications
Authors: M. Fitra Zambak *, Samir Salem Al-Bawri *, Muzammil Jusoh, Ali H. Rambe, Hamsakutty Vettikalladi, Ali M. Albishi, Mohamed Himdi
Received: 23 March 2023
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Submitted to section: Optoelectronics,
https://www.mdpi.com/journal/electronics/sections/optoelectronics
Antennas for IoT Devices
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2. First revision: Major revision (7-4-2023)

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[Electronics] Manuscript ID: electronics-2330743 - Major Revisions

Electronics Editorial Office <electronics@mdpi.com> Fri, Apr 7, 2023 at 1:26 PM
Reply-To: lucia.zhang@mdpi.com

Dear Dr. Fitra,

Thank you again for your manuscript submission:

Manuscript ID: electronics-2330743
Type of manuscript: Article
Title: A Modified Compact 2.4 GHz L-Shaped Microstrip Patch Antenna with Gain Enhancement for ISM-Band Internet of Things (IoT) Applications
Authors: M. Fitra Zambak *, Samir Salem Al-Bawri *, Muzammil Jusoh, Ali H. Rambe, Hamsakutty Vettikalladi, Ali M. Albishi, Mohamed Himdi
Received: 23 March 2023
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Submitted to section: Optoelectronics,
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Do not hesitate to contact us if you have any questions regarding the revision of your manuscript. We look forward to hearing from you soon.

Kind regards,
Mrs. Lucia Zhang
E-Mail: lucia.zhang@mdpi.com

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Thu, Apr 13, 2023 at 12:07 PM

3. The author’s request for a postponement of time due to the many revisions (13-4-2023)

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[Electronics] Manuscript ID: electronics-2330743 - Major Revisions

Thu, Apr 13, 2023 at 12:07 PM

To: lucia.zhang@mdpi.com
Cc: Electronics Editorial Office <electronics@mdpi.com>

Dear Mrs. Lucia
Greetings

As many comments need to be addressed, could you please extend our resubmission time so we can finalize and address all comments properly?

Your cooperation is highly appreciated
Thank you in advance

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4. Revised version submitted (26-4-2023)
    - Revisions Report and Amends

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To:
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Dear Dr. Fitra,

Thank you very much for resubmitting the modified version of the following manuscript:

Manuscript ID: electronics-2330743
Type of manuscript: Article
Title: A Modified Compact 2.4 GHz L-Shaped Microstrip Patch Antenna with Gain Enhancement for ISM-Band Internet of Things (IoT) Applications
Authors: M. Fitra Zambak *, Samir Salem Al-Bawri *, Muzammil Jusoh, Ali H. Rambe, Hamsakutty Vettikalladi, Ali M. Albishi, Mohamed Himdi
Received: 23 March 2023
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Submitted to section: Optoelectronics,
https://www.mdpi.com/journal/electronics/sections/optoelectronics
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Journal: Electronics (https://www.mdpi.com/journal/electronics) (ISSN 2079-9292)

Manuscript ID: electronics-2330743

Type: Article

Title: A Compact 2.4 GHz L-Shaped Microstrip Patch Antenna for ISM-Band Internet of Things (IoT) Applications (https://www.mdpi.com/2079-9292/12/9/2149)

Authors: M. Fitra Zambak * , Samir Salem Al-Bawri * (https://sciprofiles.com/profile/788233) , Muzammil Jusoh (https://sciprofiles.com/profile/730849) , Ali H. Rambe (https://sciprofiles.com/profile/2933842) , Hamsakutty Vettikalladi (https://sciprofiles.com/profile/518999) , Ali M. Albishi (https://sciprofiles.com/profile/87127) , Mohamed Himdi (https://sciprofiles.com/profile/207396)

Section: Optoelectronics (https://www.mdpi.com/journal/electronics/sections/optoelectronics)

Special Issue: Antennas for IoT Devices (https://www.mdpi.com/journal/electronics/special_issues/PFP0V63677)

Abstract: Wireless communication technology integration is necessary for Internet of Things (IoT)-based applications to make their data easily accessible. In this study, a new, portable L-shaped microstrip patch antenna with enhanced gain for IoT 2.4 GHz Industrial, Scientific, and Medical (ISM) applications is proposed. The overall dimension of the antenna is 28 × 21×1.6 mm3. The antenna design is simply comprised of an L-shape strip line with a full ground applied in the back side integrated with a tiny rectangular slot. According to investigations, the developed antenna is more efficient and has a greater gain than conventional antennas. The flexibility of the antenna matching impedance and performance are investigated through several parametric simulations. Results indicate that by modifying the back rectangular slot in conjunction with fine-tuning the front L-shaped patch, the gain and efficiency can be enhanced. The finalized antenna operates at 2.42 GHz with a 98 percent radiation efficiency and a peak gain of 1.8 dBi (measured) and 1.9 dBi (simulated). The performance of the simulation and the measurement are found to be in good agreement. With the performance that was achieved, the developed L-shaped antenna can be used in a variety of 2.4 GHz ISM bands, IoT application environments, and fourth-generation (4G) wireless communications applications of its small size and high fractional bandwidth.

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Authors' Responses to Reviewer's Comments (Reviewer 1)

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	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	( )	( )	(x)	( )
Are all the cited references relevant to the research?	( )	( )	(x)	( )
Is the research design appropriate?	( )	(x)	( )	( )
Are the methods adequately described?	( )	(x)	( )	( )
Are the results clearly presented?	( )	( )	(x)	( )
Are the conclusions supported by the results?	( )	( )	(x)	( )

Comments and Suggestions for Authors

Authors presented a L-shaped antenna for 2.4 GHz ISM band applications. Although the work is interesting but there are many technical flaws in the study.

In the title the author claimed "Gain Enhancement", however, throughout the study no such study was performed. Author must explain how they improve the gain of the antenna.

The author claimed that the proposed antenna is potential candidate for IoT applications. However, no such type of scenario based study is done. Please refer to the "Integrated Microwave and mm-Wave MIMO Antenna Module with 360∘ Pattern Diversity For 5G Internet-of-Things" and add some scenario based study or at least the link budget of the proposed antenna.

For the designing of the compact antennas for 2.4 GHz ISM band applications, faractal antennas are one of best technique as explained in A Compact, low-profile fractal antenna for wearable on-body WBAN applications and Ultra-thin flexible fractal antenna for 2.45 GHz application with wideband harmonic rejection. The use of truncated corners is also another well studied technique to achieve compact antenna for microwave as proposed in A frequency-reconfigurable filtenna for GSM, 4G-LTE, ISM, and 5G Sub-6 GHz band applications and 2.45-GHz wideband harmonic rejection rectenna for wireless power transfer. Along with that open ended stub loading technqiue is alos widely studied as explained in A low-profile antenna for on-body and off-body applications in the lower and upper ISM and WLAN bands or in A compact MIMO antenna with improved isolation for ISM, sub-6 GHz, and WLAN application. The authors must add a comparative study in the introduction to provide an in depth review to the readers.

The introduction part need to add some-state-of-the-art literature review portion as well. This will be done by adding reference work from last 5 years and then find the potential research gap that authors tried to fullfill in this study. Some suggest state-of-the-art are:

10.1109/ACCESS.2022.3219442

10.23919/APMC55665.2022.9999876

10.1109/LAWP.2016.2598729

10.1109/AP-S/USNC-URSI47032.2022.9887033

10.1109/TAP.2021.3069422

How the dimension of the feed-line and the slot is determined initially?

No information can be extracted from the current graphs. Authors are requested to add current graph comparison for resonating and non-resonating band to depicts the exact information.

It is highly recommended to add some on-body performance as well, or atleast putting antenna on some object as the targetted application is IoT.

What does it mean by -5ns in the group delay, kindly explain.

What is the distance between antenna elements for S21 calculation. Antennas are placed side by side, face by face or non-face to face. Please explain and add the S12 for other cases as well.

Comparison table need to be updated by only citing the papers published in last 5 year, adding older paper make the proposed work of no worth.

Author must add the antenna length in term of their electrical length.

The remark column can be removed, as it make the reader confused about what type of information is their.

Submission Date	23 March 2023
Date of this review	27 Mar 2023 03:44:05

Response to Reviewer 1 Comments

Point 1: Authors presented a L-shaped antenna for 2.4 GHz ISM band applications. Although the work is interesting but there are many technical flaws in the study.
In the title the author claimed "Gain Enhancement", however, throughout the study no such study was performed. Author must explain how they improve the gain of the antenna.
Response 1: Thank you for this notifacation.
The simulated radiation efficiency is found to reach about 98%, which is much greater than that of the reported microstrip antennas with a same substrate. These characteristics is considereded to be the reason for the enhanced antenna gain here. The increase in the radiation efficiency is largely associated to the embedded the rectangular slot in the ground plane, which higly effective to the patch surface current paths of the proposed antenna. Some analysis are given in the new version as shown in Fig 8.

Point 2: The author claimed that the proposed antenna is potential candidate for IoT applications. However, no such type of scenario based study is done. Please refer to the "Integrated Microwave and mm-Wave MIMO Antenna Module with 360∘ Pattern Diversity For 5G Internet-of-Things" and add some scenario based study or at least the link budget of the proposed antenna.
Response 2: Thank you for the valublae suggession. We have addded a section #5 for the use of the proposed antenna on IoT application based on the revewer suggestion

Point 3: For the designing of the compact antennas for 2.4 GHz ISM band applications, faractal antennas are one of best technique as explained in A Compact, low-profile fractal antenna for wearable on-body WBAN applications and Ultra-thin flexible fractal antenna for 2.45 GHz application with wideband harmonic rejection. The use of truncated corners is also another well studied technique to achieve compact antenna for microwave as proposed in A frequency-reconfigurable filtenna for GSM, 4G-LTE, ISM, and 5G Sub-6 GHz band applications and 2.45-GHz wideband harmonic rejection rectenna for wireless power transfer. Along with that open ended stub loading technqiue is alos widely studied as explained in A low-profile antenna for on-body and off-body applications in the lower and upper ISM and WLAN bands or in A compact MIMO antenna with improved isolation for ISM, sub-6 GHz, and WLAN application. The authors must add a comparative study in the introduction to provide an in depth review to the readers.
The introduction part need to add some-state-of-the-art literature review portion as well. This will be done by adding reference work from last 5 years and then find the potential research gap that authors tried to fullfill in this study. Some suggest state-of-the-art are:
10.1109/ACCESS.2022.3219442
10.23919/APMC55665.2022.9999876
10.1109/LAWP.2016.2598729
10.1109/AP-S/USNC-URSI47032.2022.9887033
10.1109/TAP.2021.3069422

Response 3: Thanks for this valuble comment which will help to improve our manscript. The abovementioned refereances have been added and disccssed in the introduction.

Point 4: How the dimension of the feed-line and the slot is determined initially?

Response 4: Thank you for this comment.

The width of the conducting layer is important to calculate the radiation intensity since it directly affects the bandwidth of the signal waves. To find out the width based on the Z impedanse (50 ohm) of the feed line the following calculator has beed used

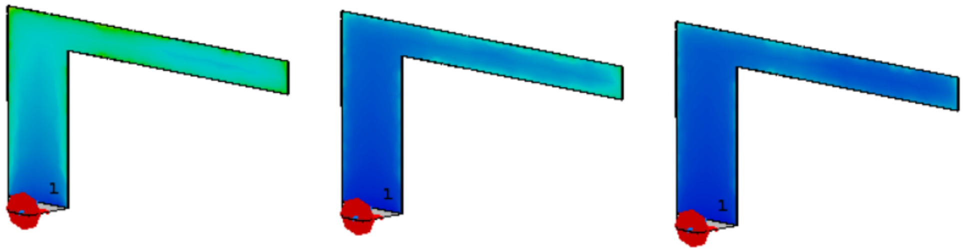
https://www.emtalk.com/mscalc.php

However, the slot has been created based on the affected area on the ground plan and it was optimised acordingly to satisfy the our inquriry

Point 5: No information can be extracted from the current graphs. Authors are requested to add current graph comparison for resonating and non-resonating band to depicts the exact information.

Response 5: Thank you for effort to improve our manscript

New graphs for current distrbitions have been added with explinations.



(b) (c) (d)

Point 6: It is highly recommended to add some on-body performance as well, or atleast putting antenna on some object as the targetted application is IoT.

Response 6: Thank you for your suggestions. However, our upcoming work will inculd this antenna with sveral implmentations inclding on body performance. So, if you don't mind we will keep this to the upcoming forseen work. Thanks

Point 7: What does it mean by -5ns in the group delay, kindly explain.

Response 7: Please

The group delay of lower band antenna is shown to be around 1.3ns,whereasa 22ns in higher bands which means the frequency derivative of the far-field phase, can add to the ionospheric delay and various other error terms to reduce the overall accuracy of the positioning information.

Furthermore, the group delay is used to calculate a signal delay value.

Point 8: What is the distance between antenna elements for S21 calculation. Antennas are placed side by side, face by face or non-face to face. Please explain and add the S12 for other cases as well.

Response 8: Thank you. This antenna is condidereed as one port so there is no calculation transmission calculation S21

Point 9: Comparison table need to be updated by only citing the papers published in last 5 year, adding older paper make the proposed work of no worth.

Response 9: Thank you for your effort to improve our manscript. The table has been updated accordingly in the current version.

Point 10: Author must add the antenna length in term of their electrical length.

Response 10: Thank you for valuable comment. The electrical length has been added in the new version of manscript.

Point 11: The remark column can be removed, as it make the reader confused about what type of information is their.

Response 11: The remark column remaved as suggested by the reviewer. Thank you.

Journal	Electronics (https://www.mdpi.com/journal/electronics) (ISSN 2079-9292)
Manuscript ID	electronics-2330743
Type	Article
Title	A Compact 2.4 GHz L-Shaped Microstrip Patch Antenna for ISM-Band Internet of Things (IoT) Applications (https://www.mdpi.com/2079-9292/12/9/2149)
Authors	M. Fitra Zambak * , Samir Salem Al-Bawri * (https://sciprofiles.com/profile/788233) , Muzammil Jusoh (https://sciprofiles.com/profile/730849) , Ali H. Rambe (https://sciprofiles.com/profile/2933842) , Hamsakutty Vettikalladi (https://sciprofiles.com/profile/518999) , Ali M. Albishi (https://sciprofiles.com/profile/87127) , Mohamed Himdi (https://sciprofiles.com/profile/207396)
Section	Optoelectronics (https://www.mdpi.com/journal/electronics/sections/optoelectronics)
Special Issue	Antennas for IoT Devices (https://www.mdpi.com/journal/electronics/special_issues/PFP0V63677)
Abstract	Wireless communication technology integration is necessary for Internet of Things (IoT)-based applications to make their data easily accessible. In this study, a new, portable L-shaped microstrip patch antenna with enhanced gain for IoT 2.4 GHz Industrial, Scientific, and Medical (ISM) applications is proposed. The overall dimension of the antenna is 28 × 21×1.6 mm3. The antenna design is simply comprised of an L-shape strip line with a full ground applied in the back side integrated with a tiny rectangular slot. According to investigations, the developed antenna is more efficient and has a greater gain than conventional antennas. The flexibility of the antenna matching impedance and performance are investigated through several parametric simulations. Results indicate that by modifying the back rectangular slot in conjunction with fine-tuning the front L-shaped patch, the gain and efficiency can be enhanced. The finalized antenna operates at 2.42 GHz with a 98 percent radiation efficiency and a peak gain of 1.8 dBi (measured) and 1.9 dBi (simulated). The performance of the simulation and the measurement are found to be in good agreement. With the performance that was achieved, the developed L-shaped antenna can be used in a variety of 2.4 GHz ISM bands, IoT application environments, and fourth-generation (4G) wireless communications applications of its small size and high fractional bandwidth.

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Authors' Responses to Reviewer's Comments (Reviewer 2)

Author's Notes	Please see the attachmen
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Quality of English Language
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( ) Extensive editing of English language and style required
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( ) English language and style are fine/minor spell check required
(x) I am not qualified to assess the quality of English in this paper

	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	(x)	( )	( )	( )
Are all the cited references relevant to the research?	(x)	( )	( )	( )
Is the research design appropriate?	(x)	( )	( )	( )
Are the methods adequately described?	(x)	( )	( )	( )
Are the results clearly presented?	( )	(x)	( )	( )
Are the conclusions supported by the results?	(x)	( )	( )	( )

Comments and Suggestions for Authors

A new portable I-shaped microstrip patch antenna for industrial, scientific and medical (ISM) applications is presented in this paper. The simulation and experimental results show that the antenna developed in this paper has higher efficiency and greater gain than the traditional antenna. But the paper lacks the principle analysis of this design, and the parameter optimization process is not enough, can not support the conclusion well。

Submission Date	23 March 2023
Date of this review	30 Mar 2023 09:30:39

Response to Reviewer 2 Comments

Point 1: A new portable I-shaped microstrip patch antenna for industrial, scientific and medical (ISM) applications is presented in this paper. The simulation and experimental results show that the antenna developed in this paper has higher efficiency and greater gain than the traditional antenna. But the paper lacks the principle analysis of this design, and the parameter optimization process is not enough, can not support the conclusion well

Response 1: Thank you for the positive feedback.
Several analysis steps on the proposed antenna design have been added in the new version of the manuscript. Furthermore, the conclusion has been modified. Thanks

5. Second revision: Major revisions (1-5-2023)

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[Electronics] Manuscript ID: electronics-2330743 - Major Revisions (deadline: 6 May 2023)

1 message

Electronics Editorial Office <electronics@mdpi.com> Mon, May 1, 2023 at 8:48 AM
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Dear Dr. Al-Bawri,

Thank you again for your manuscript submission:

Manuscript ID: electronics-2330743
Type of manuscript: Article
Title: A Compact 2.4 GHz L-Shaped Microstrip Patch Antenna for ISM-Band Internet of Things (IoT) Applications
Authors: M. Fitra Zambak *, Samir Salem Al-Bawri *, Muzammil Jusoh, Ali H. Rambe, Hamsakutty Vettikalladi, Ali M. Albishi, Mohamed Himdi
Received: 23 March 2023
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Type: Article

Title: A Compact 2.4 GHz L-Shaped Microstrip Patch Antenna for ISM-Band Internet of Things (IoT) Applications (https://www.mdpi.com/2079-9292/12/9/2149)

Authors: M. Fitra Zambak * , Samir Salem Al-Bawri * (https://sciprofiles.com/profile/788233) , Muzammil Jusoh (https://sciprofiles.com/profile/730849) , Ali H. Rambe (https://sciprofiles.com/profile/2933842) , Hamsakutty Vettikalladi (https://sciprofiles.com/profile/518999) , Ali M. Albishi (https://sciprofiles.com/profile/87127) , Mohamed Himdi (https://sciprofiles.com/profile/207396)

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Abstract: Wireless communication technology integration is necessary for Internet of Things (IoT)-based applications to make their data easily accessible. In this study, a new, portable L-shaped microstrip patch antenna with enhanced gain for IoT 2.4 GHz Industrial, Scientific, and Medical (ISM) applications is proposed. The overall dimension of the antenna is 28 × 21×1.6 mm3. The antenna design is simply comprised of an L-shape strip line with a full ground applied in the back side integrated with a tiny rectangular slot. According to investigations, the developed antenna is more efficient and has a greater gain than conventional antennas. The flexibility of the antenna matching impedance and performance are investigated through several parametric simulations. Results indicate that by modifying the back rectangular slot in conjunction with fine-tuning the front L-shaped patch, the gain and efficiency can be enhanced. The finalized antenna operates at 2.42 GHz with a 98 percent radiation efficiency and a peak gain of 1.8 dBi (measured) and 1.9 dBi (simulated). The performance of the simulation and the measurement are found to be in good agreement. With the performance that was achieved, the developed L-shaped antenna can be used in a variety of 2.4 GHz ISM bands, IoT application environments, and fourth-generation (4G) wireless communications applications of its small size and high fractional bandwidth.

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For the designing of the compact antennas for 2.4 GHz ISM band applications, faractal antennas are one of best technique as explained in A Compact, low-profile fractal antenna for wearable on-body WBAN applications and Ultra-thin flexible fractal antenna for 2.45 GHz application with wideband harmonic rejection. The use of truncated corners is also another well studied technique to achieve compact antenna for microwave as proposed in A frequencyreconfigurable filtenna for GSM, 4G-LTE, ISM, and 5G Sub-6 GHz band applications and 2.45-GHz wideband harmonic rejection rectenna for wireless power transfer. Along with that open ended stub loading technqiue is alos widely studied as explained in A low-profile antenna for on-body and offbody applications in the lower and upper ISM and WLAN bands or in A compact MIMO antenna with improved isolation for ISM, sub-6 GHz, and WLAN application. The authors must add a comparative study in the introduction to provide an in depth review to the readers. The introduction part need to add some-state-of-the-art literature review portion as well. This will be done by adding reference work from last 5 years and then find the potential research gap that authors tried to fullfill in this study. Some suggest state-of-the-art are:

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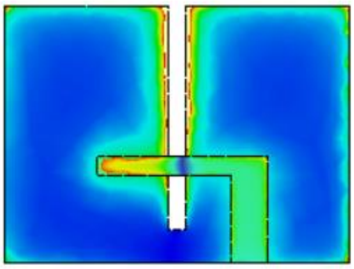

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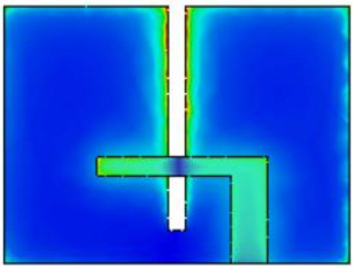

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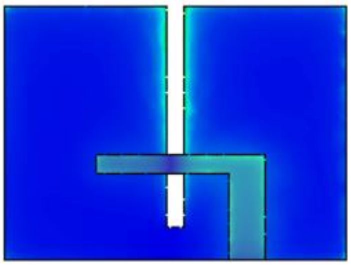

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Abstract

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Article

A Compact 2.4 GHz L-Shaped Microstrip Patch Antenna for ISM-Band Internet of Things (IoT) Applications

M. Fitra Zambak [1,*], Samir Salem Al-Bawri [2,*], Muzammil Jusoh [3], Ali Hanafiah Rambe [4], Hamsakutty Vettikalladi [5], Ali M. Albishi [5] and Mohamed Himdi [6]

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Abstract: Wireless communication technology integration is necessary for Internet of Things (IoT)-based applications to make their data easily accessible. This study proposes a new, portable L-shaped microstrip patch antenna with enhanced gain for IoT 2.4 GHz Industrial, Scientific, and Medical (ISM) applications. The overall dimensions of the antenna are 28 mm × 21 mm × 1.6 mm (0.22 λ_o × 0.17λ_o × 0.013λ_o, with respect to the lowest frequency). The antenna design is simply comprised of an L-shape strip line, with a full ground applied in the back side and integrated with a tiny rectangular slot. According to investigations, the developed antenna is more efficient and has a greater gain than conventional antennas. The flexibility of the antenna's matching impedance and performance are investigated through several parametric simulations. Results indicate that the gain and efficiency can be enhanced through modifying the rectangular back slot in conjunction with fine-tuning the front L-shaped patch. The finalized antenna operates at 2.4 GHz with a 98% radiation efficiency and peak gains of 2.09 dBi (measured) and 1.95 dBi (simulated). The performance of the simulation and measurement are found to be in good agreement. Based on the performance that was achieved, the developed L-shaped antenna can be used in a variety of 2.4 GHz ISM bands and IoT application environments, especially for indoor localization estimation scenarios, such as smart offices and houses, and fourth-generation (4G) wireless communications applications due to its small size and high fractional bandwidth.

Keywords: Internet of Things; antenna; gain; bandwidth

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1. Introduction

The idea of the Internet of Things (IoT) has now been integrated into the Internet. It is a rapidly expanding global network of linked things that supports several input–output devices, sensors, and actuators using a common communication protocol. The effectiveness of IoT application operation and device internet connectivity are both enhanced using wireless sensor technologies [1]. With the rapid advancement of IoT technologies, ever-more applications are being found in a variety of fields, such as agriculture, tracking, security, smart cities, smart homes, etc. The antenna is one of the key components of wireless communication sensor technology that is moving into the future. Over the past few years, small and readily integrated antenna design drew a lot of attention due to the enhanced potential for using multi-frequency and multi-function antenna in communication

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technologies [2]. The unlicensed 2.4 GHz band used for industrial, scientific, and medical purposes transmits the combined communication data at a high frequency band. For IoT applications, the applications of a transparent loop antenna that allows deployment at various locations are also shown [3]. In [4], a planar multiple-input and multiple-output (MIMO) antenna for IoT applications was created. In [5], a loop antenna for biotelemetry Internet of Things applications was developed. A leaky-wave antenna with a fractional bandwidth of 136.5% was created in [6] for scanning applications of passive radar systems. This antenna can function with Bluetooth Low Energy (BLE), Global System for Mobile Communication 900° (GSM 900), and GSM 1800. [7]; a planar antenna with an omnidirectional radiation pattern and a fractional bandwidth of 143.66% was designed for use in Global Positioning System (GPS), Bluetooth, and Wireless Fidelity (WiFi) applications. Therefore, the primary factors that must be considered when constructing microstrip patch antennas operating in the 2.4 GHz band are radiation and total efficiencies, bandwidth (BW), radiation pattern, gain, etc. [8–10].

The wireless communication sector requires tiny, lightweight antennas with affordable fabrication [11]. As it is designed to achieve low profile reduction via implanting wire construct on a dielectric substrate, a miniaturized meander-shaped antenna is a viable option in this situation because the space available for its installation is constrained [12]. An antenna with a smaller size and fixed frequency operation was presented as a compact meandering slotted microstrip antenna [13]. Additionally, low bandwidth and low gain antennas present another difficulty for communication systems. Researchers have put forth a variety of methods for improving gain, BW and efficiency, with acceptable radiation characteristics utilizing several antennas with complicated shapes. The single frequency and small bandwidth of a microstrip antenna are two significant drawbacks. To address this problem, a tuning stub resembling a fork is attached to the microstrip slotted antenna [14]. On a 1.6 mm thick FR-4 substrate, a capacitive load (C-load) was applied to increase peak gain with a fractional BW of 7.23% and improve impedance matching, which represents a distinguished performance enhancement approach [15]. To increase the fractional bandwidth, embedded metamaterials were also used [16,17]. However, applying a parasitic patch to the antenna is a useful technique for increasing the BW and gain. The bandwidth and gain are increased by approximately 3.3 dB [18] when the parasitic patch is situated close to the feed patch. Mobile phones for 2.4 GHz have parasitic patches installed with an inverted F-antenna, and the impedance bandwidth is 90 MHz [19]. Using a parasitic element, which acts as a director in the low working range between 1.6 and 3.45 GHz, impedance matching was enhanced [20]. The circular disc monopole antenna was also given shaped ground in order to match its 50-ohm impedance [21]. When parasitic elements are applied to the microstrip antenna at frequencies of 2.99–3.10 GHz and 2.1–11.1 GHz, respectively, the impedance bandwidth likewise increases from 4.3% to 6% and 136% [22,23].

For the designing of compact antennas for 2.4 GHz ISM band applications, fractal antennas are one of best available techniques, as explained in [24,25]. The use of truncated corners is another well-studied technique to achieve compact antenna for microwave, as proposed in [26,27]. The open-ended stub loading technique is also widely studied, as explained in [28,29]. To obtain a satisfactory impedance fractional bandwidth of 2.4 GHz, a variety of different-shaped antennas of various sizes were proposed and measured [24–27]. For biotelemetry in biomedical investigative systems, a small, strong, and flexible body-worn antenna was presented in [30]. In order to ensure that the antenna is of the ideal size and works at a lower frequency band of interest, the fractal-based design lengthened the current flow. WMTS and ISM bands are simultaneously covered using the antenna's dual-band operation (1.38–1.8 GHz and 2.25–4.88 GHz). However, [31] presents a dual-band antenna for on - and off-body communications in the ISM frequencies bands of 2.45 GHz and 5.8 GHz, with silver material combined onto a stretchable polydimethylsiloxane (PDMS) substrate, which is more useful for wearable applications. In [32], a compact antenna-based PDMS with an overall size of 14 × 33 mm2 was introduced with a

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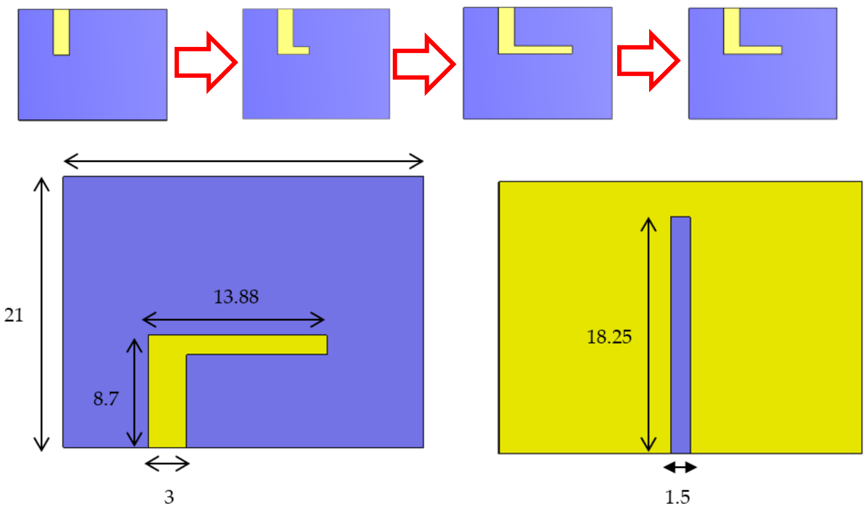
15% broadband offering and centered at 2.45 GHz. In contrast, a conformal antenna with electronic tuning capability was presented in [33]; it involves a 40 mm bending radius using a PDMS substrate, with 64% being the achieved efficiency in the broadside mode.

This paper reports a well-modified L-shaped compact antenna for 2.4 GHz ISM band IoT applications. The simulation was conducted using the Computer Simulation Technology (CST) Microwave Studio simulator. For experimental measurements, the antenna was constructed on a Rogers 5880 printed circuit board. A straightforward L-shaped strip line was attached to the feed SMA connector in this design, and integrated with an etching slot built on the backside to obtain sufficient gain and bandwidth. It is demonstrated that a ground shape can provide the gain at a constant value while improving both bandwidth and efficiency results. Additionally, an experiment to assess the performance of the antenna is provided, and the findings show that the results are in good agreement with the simulation.

2. Antenna Design

The proposed L-shaped antenna (Figure 1) was constructed on a Rogers 5880 substrate, with ε_r = 2.2 permittivity, thickness of 1.57 mm, and loss tangent = 0.0009. The antenna measured 28 mm × 21 mm in dimensions. The microstrip patch was two perpendicular lines forming an inverted L-shape to produce the main radiator. The proposed main radiator was designed as a simple microstrip strip line patch, which was directly linked to the port feeding. It was followed by a perpendicular line that formed an L-shape, which was modified and optimized within several steps to find the optimal band of interest at 2.4 GHz, as demonstrated in Figure 1. The proposed antenna's impedance was 51 ohms, whereas the feed line was linked to matching a 50-ohm impedance. In order to find the impedance-matching bandwidth, a rectangular slot was also created in the ground plane's middle section, not far from the feed line. Using parametric study for various values, the impact of the L shape and ground slot was clarified. The proposed antenna was created and measured to confirm its validity. Figure 2 shows the fabricated antenna.



(**a**) (**b**)

Figure 1. Antenna topology: (**a**) front patch, (**b**) back side ground plane.

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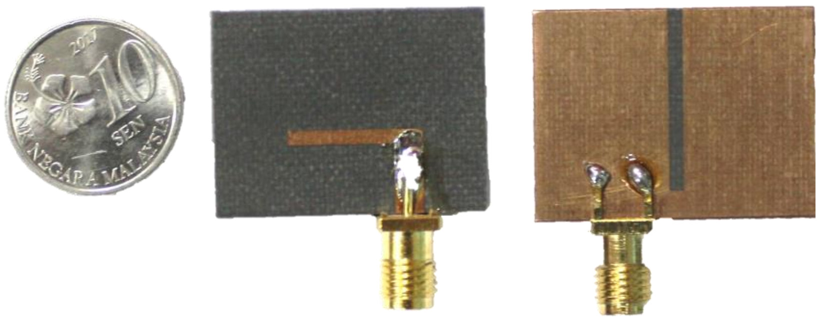


(a) **(b)**

Figure 2. Fabricated prototype: (**a**) patch, (**b**) backside ground.

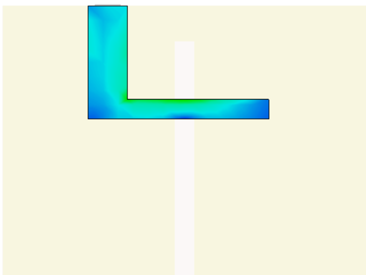
3. Parametric Study Working Principles

The structure's key parameters are illustrated in later parts to show how they affect its functionality. The proposed antenna performance depends mainly on the dimensions of the L-shaped strip, as well as the height and width of the aperture at the ground plane.

3.1. Working Principles

The simulated current distribution is examined and studied in order to shed light on the characteristics and operating principles of the proposed antenna. Figure 3a displays the antenna's current distribution at 2.4 GHz. The radiating element of the proposed antenna demonstrates that the principal radiator is the region of the external edges of the L radiating element, where the majority of the current distribution is focused. However, the patch's high current distribution on the upper side of the L shape helps the antenna's resonance through shifting it at 2.4 GHz, while the antenna's expanded top portion of the L shape has an impact on its gain due to the appearance of the extraordinary current on the upper part.

Figure 3b displays the surface current distribution in the upper antenna arm at the resonant frequency of 2.44 GHz, whereas the whole structure exhibits single-order resonance properties. The L shape with a backside slot cut in the ground perturbs the current distribution, creating resonance at 2.4 GHz. However, the antenna's operation in the slightly shifted frequencies of 2.48 GHz and 2.58 GHz can be attributed to two distinct minima, which are seen for the current for both cases: one at the end of the arm and the other at several points in the upper edge. In contrast, low current concentration via the L shape is achieved in the case of non-resonating bands, as seen in Figure 3c,d.



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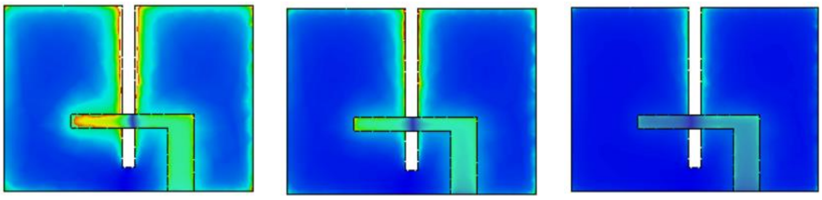

Figure 3. Simulated of optimized antenna current distribution.

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3.2. Aperture's Length (L) and Width (W)

The aperture slot length (L) and width (W) affect the resonance frequency bandwidth significantly, as illustrated in Figure 4.

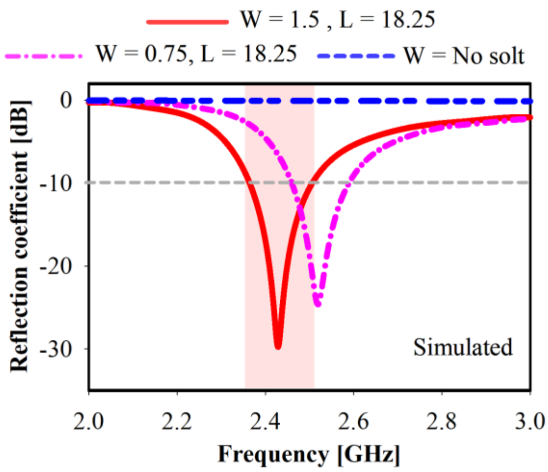

Figure 4. Simulated reflection coefficients for different antenna lengths (L).

Narrower W with 0.75 mm shifts the bandwidth towards a higher frequency. Both L and W are varied together, whereas the resonance at 2.4 GHz totally disappears in the case of no slot. However, slot L = 18.25 mm and W= 1.5 mm are the optimal dimensions for the achieved bandwidth.

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3.3. Patch's Length (LP) and Width (WP)

It is observed that the increment of the patch's line length (LP) leads to enlarged bandwidths at 2.4 GHz. Figure 5 demonstrates the simulated reflection coefficient of the proposed antenna. LP is kept above −10 dB in the case of sort LP at 8 mm, whereas the resonance at 2.4 GHz starts to disappear. Furthermore, no resonance can be seen when LP = 3 mm. The optimum value for the LP is 18.25, which is chosen to attain the targeted operating frequency band. However, a very narrow bandwidth is observed when the patch's width WP = 1 mm and the length remains constant at 18.25 mm, as illustrated in Figure 6. This resonance will be continuously reduced if the WP decreases accordingly.

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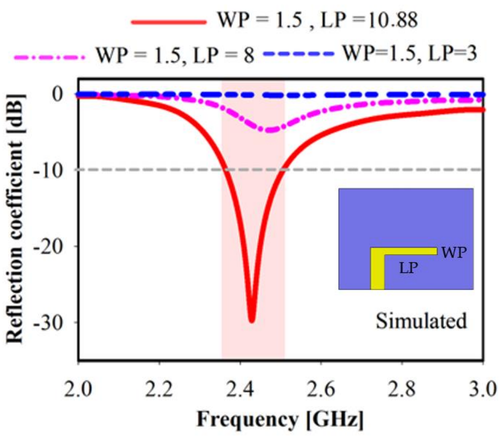

Figure 5. Simulated different patch's length reflection coefficient.

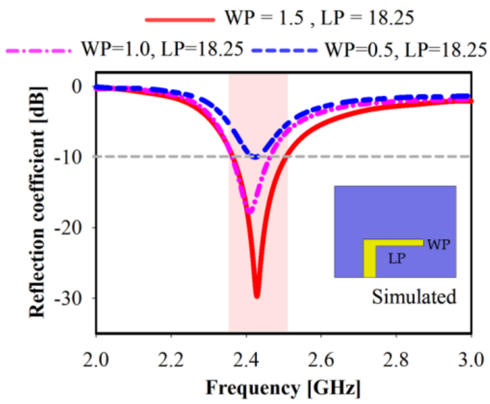

Figure 6. Simulated different patch widths reflection coefficient.

4. Results and Discussion

To ensure the greatest performance in terms of the band of interest, bandwidth, compact size, and gain, a number of crucial characteristics of the proposed L-shaped antenna were optimized prior to the choice and manufacture of the final structure. The simulation and measurement of the final prototype's reflection coefficient are shown in Figure 7. The antenna's final optimized overall dimensions are 28 mm × 21 mm × 1.6 mm. The proposed antenna's realized bandwidth spans a minimum of 2.36 GHz and a maximum of 2.5 GHz (with a total of 145 MHz, i.e., 5.8%). Figure 8 illustrates the efficiency of the L-shaped antenna. The exhibited radiation and total efficiencies have peaks of 98% and 97%, respectively, at 2.4 GHz. In addition, the achieved gain of the proposed single antenna in the operation bandwidth is defined. The realized gain can reach up to 2.09 dBi, though it decreases slightly towards a lower frequency range, as demonstrated in Figure 8. The simulated and measured findings showed a good agreement. Furthermore, Figure 9 displays

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the achieved simulated gain with different widths of the slot placed on the ground plane; this figure shows the effect of that slot on achieving high realized gain on the 1.5 mm width.

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Figure 10 displays the simulated and measured 2.4 GHz azimuth-plane radiation patterns. The antenna radiates in the H-plane with modest amounts of cross-polarization and vertical polarization (xz-plane). The proposed antenna has a figure-of-eight radiation pattern at 2.4 GHz in the E-plane (yz-plane). Figure 11 shows the S11 reflection coefficient and radiation pattern measurement setup for the proposed antenna.

Figure 12 depicts the simulated face-to-face group delay (GD) of the suggested compact antenna. Over the frequency range, it is almost homogeneous with little change (1.3 ns). As a result, it is clear that there was no signal distortion between the transmitting and receiving antenna systems. Additionally, the transfer function (TF) in Figure 10 with the transmission coefficient S21 exhibits reduced distortion. As a result, this antenna is suited to use in IoT and short-range communications applications because of the realized TF and flat GD over the frequency range.

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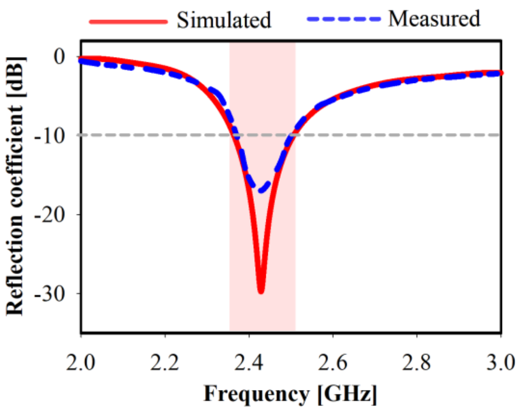

Figure 7. Simulated and measured reflection coefficient.

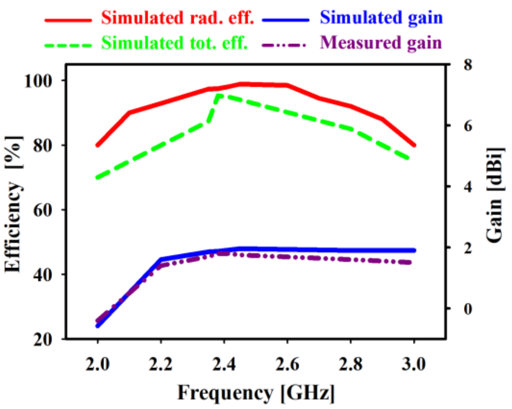

Figure 8. Simulated and measured gain, radiation efficiency, and total efficiency for proposed antenna.

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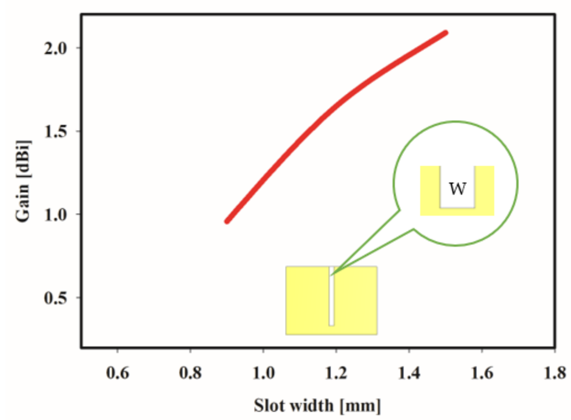

Figure 9. Simulated analysis of gain.

The suggested antenna is contrasted with the current microstrip antenna at 2.4 GHz in Table 1. A variety of 2.4 GHz antenna topologies were reported by researchers, together with parametric and experimental results for various applications. The comparison demonstrates that, in contrast to all of the other designs, the proposed compact antenna has a higher gain. The comparison table makes clear that existing antenna dimensions are typically bigger than those of the suggested antenna. Furthermore, the performance of the proposed antenna at 2.4 GHz is better than others, and is a workable solution for 2.4 GHz IoT.

Table 1. Performance comparison for state of proposed L-shaped antenna at 2.4 GHz.

Year	Ref.	Antenna Shape	Antenna Size	Fractional BW (%)	Rad. Eff. (%)	Gain (dB)	Applications
2014	11	Meander line	32.00 × 01.60	7.60	-	0.50	NS
2017	34	Spiral slot	12.45 × 13.05	7.50	-	1.33	NS
2018	35	Uniplanar	10.00 × 19.00	8.00	-	1.20	2.5 GHz applications
2018	36	Bowtie antenna	29.00 × 13.70	-	89	1.47	Wearable application
2019	37	Meander line	40.00 × 10.00	12.5	79	1.34	IoT
2020	40	Slotted SIW	120.0 × 395.4	2.10	-	4.80	WLAN
2021	41	Slot antenna	105.0 × 85.00	3.20	-	4.00	IoT
2022	42	Cage antenna	49.00 × 49.00	3.20	93	3.00	WLAN
2023	This study	L-shaped	28.00 × 21.00	5.80	98	2.09	IoT

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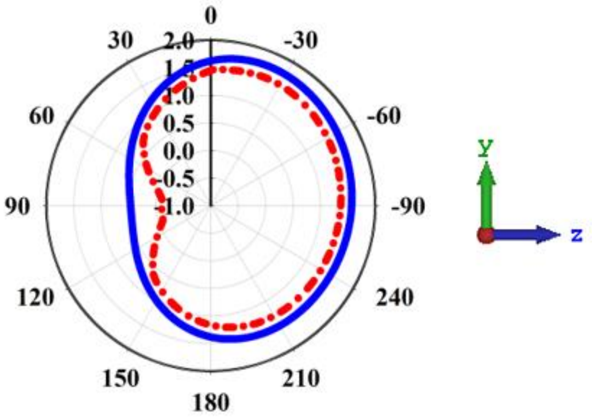
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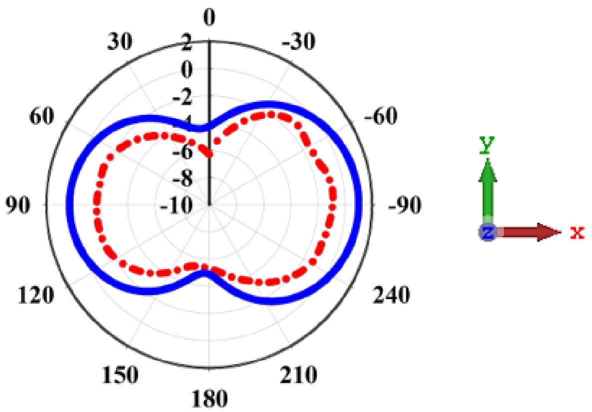
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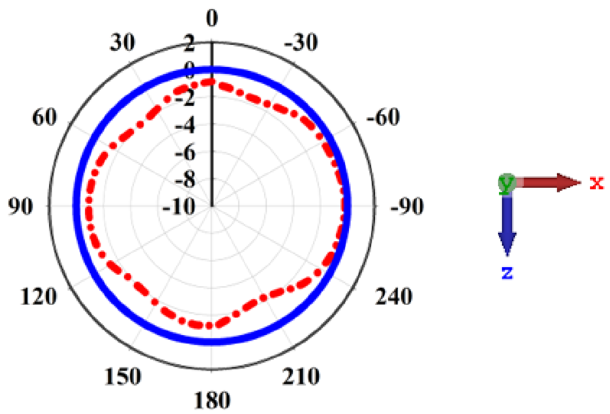

(c)

Figure 10. Two-dimensional simulated and measured radiation patterns at 2.4 GHz for planes: (**a**) YZ (Ø = 90°), (**b**) XY (θ = 90°), (**c**) XZ (Ø = 0°).

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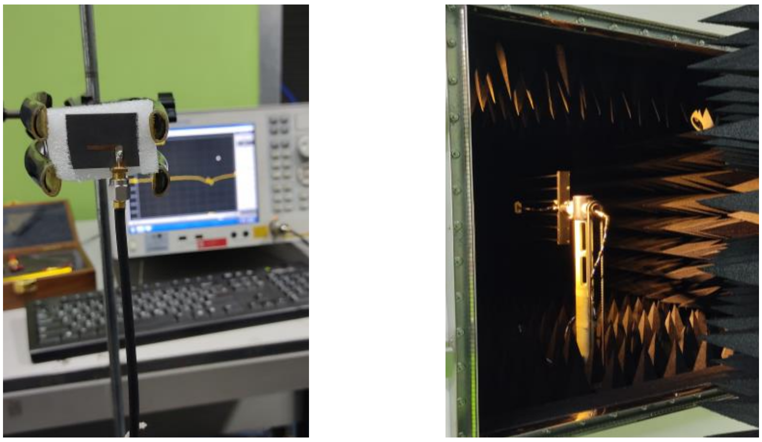

(a) **(b)**

Figure 11. Measurement setup: (**a**) S11, (**b**) radiation pattern.

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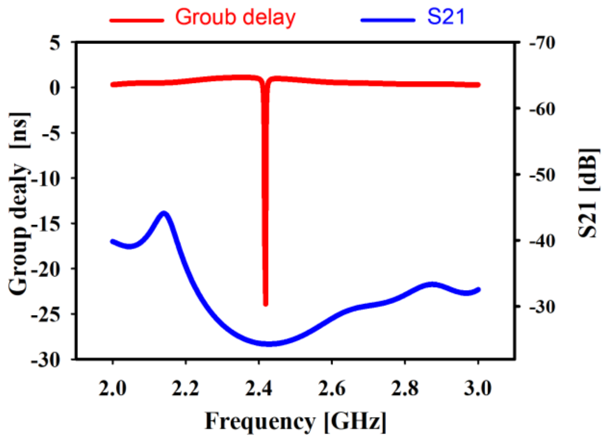

Figure 12. Face-to-face position response of group is delayed.

5. Application Scenarios

The suggested antenna can be used for various indoor communications applications, including smart homes, airports, malls, etc. These suggested uses are viable because the proposed antenna covers the significant IoT band of microwave bands. The following subsection contains an explanation of an application scenario.

5.1. Indoor Localization Systems

Future smart homes, airports, and retail centres will use microwave and mm-wave bands for indoor connectivity to facilitate multi-system wireless communication networks, whereas microwave frequency bands will offer long-range telecommunications with average speeds that link an enormous number of multi-media gadgets and IoT devices [38]. The proposed antenna will be used to collect the received signal strength (RSS) in a specific indoor scenario within different positions of the mobile station subscriber, highly identifying its location without using a global position satellite (GPS). This technique analyzes variations in RSS between one transmitter, known as a single base station (SBS), and a huge number of subscriber mobile station receivers. Therefore, it will be evaluated based on the algorithm proposed in [39] to estimate the unknown mobile station receiver positions with the SBS.

6. Conclusions

Nowadays, one of the benefits of IoT applications is the use of antenna terminals as wireless sensor technologies. In this study, a prospective solution to be utilized in IoT-based applications is introduced. The proposed compact antenna is modified and constructed as an L-shaped antenna for the ISM at the 2.4 GHz frequency band. The influence of the straightforward L-shape patch, along with an etching rectangular backside slot in the ground plane, was examined numerically and verified using measurements. The obtained results showed that the antenna had an excellent radiation efficiency of 98% and simulated attained gain up to 2.09 dBi, which are well-thought-out as special considerations compared to other conventional antennas. The proposed antenna is a viable candidate for wireless fourth-generation 4G and IoT, especially in an indoor development scenario for smart offices/homes. Upcoming work will apply the proposed antenna in radio frequency (RF) modules for IoT sensors as a transmitter for indoor localization estimation using only one base station.

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Informed Consent Statement: Please add this part.

Data Availability Statement: Please add this part.

Conflicts of Interest: The authors declare no conflicts of interest.

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Article

A Compact 2.4 GHz L-Shaped Microstrip Patch Antenna for ISM-Band Internet of Things (IoT) Applications

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Abstract: Wireless communication technology integration is necessary for Internet of Things (IoT)-based applications to make their data easily accessible. This study proposes a new, portable L-shaped microstrip patch antenna with enhanced gain for IoT 2.4 GHz Industrial, Scientific, and Medical (ISM) applications. The overall dimensions of the antenna are 28 mm × 21 mm × 1.6 mm ($0.22\lambda_o \times 0.17\lambda_o \times 0.013\lambda_o$, with respect to the lowest frequency). The antenna design is simply comprised of an L-shape strip line, with a full ground applied in the back side and integrated with a tiny rectangular slot. According to investigations, the developed antenna is more efficient and has a greater gain than conventional antennas. The flexibility of the antenna's matching impedance and performance are investigated through several parametric simulations. Results indicate that the gain and efficiency can be enhanced through modifying the rectangular back slot in conjunction with fine-tuning the front L-shaped patch. The finalized antenna operates at 2.4 GHz with a 98% radiation efficiency and peak gains of 2.09 dBi (measured) and 1.95 dBi (simulated). The performance of the simulation and measurement are found to be in good agreement. Based on the performance that was achieved, the developed L-shaped antenna can be used in a variety of 2.4 GHz ISM bands and IoT application environments, especially for indoor localization estimation scenarios, such as smart offices and houses, and fourth-generation (4G) wireless communications applications due to its small size and high fractional bandwidth.

Keywords: Internet of Things; antenna; gain; bandwidth

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1. Introduction

The idea of the Internet of Things (IoT) has now been integrated into the Internet. It is a rapidly expanding global network of linked things that supports several input–output devices, sensors, and actuators using a common communication protocol. The effectiveness of IoT application operation and device internet connectivity are both enhanced using wireless sensor technologies [1]. With the rapid advancement of IoT technologies, ever- more applications are being found in a variety of fields, such as agriculture, tracking, security, smart cities, smart homes, etc. The antenna is one of the key components of wireless communication sensor technology that is moving into the future. Over the past few years, small and readily integrated antenna design drew a lot of attention due to the enhanced potential for using multi-frequency and multi-function antenna in communication technologies [2].

The unlicensed 2.4 GHz band used for industrial, scientific, and medical purposes transmits the combined communication data at a high frequency band. For IoT applications, the applications of a transparent loop antenna that allows deployment at various locations are also shown [3]. In [4], a planar multiple-input and multiple-output (MIMO) antenna for IoT applications was created. In [5], a loop antenna for biotelemetry Internet of Things applications was developed. A leaky-wave antenna with a fractional bandwidth of 136.5% was created in [6] for scanning applications of passive radar systems. This antenna can function with Bluetooth Low Energy (BLE), Global System for Mobile Communication 900° (GSM 900), and GSM 1800 [7]; a planar antenna with an omnidirectional radiation pattern and a fractional bandwidth of 143.66% was designed for use in Global Positioning System (GPS), Bluetooth, and Wireless Fidelity (WiFi) applications. Therefore, the primary factors that must be considered when constructing microstrip patch antennas operating in the 2.4 GHz band are radiation and total efficiencies, bandwidth (BW), radiation pattern, gain, etc. [8–10].

The wireless communication sector requires tiny, lightweight antennas with affordable fabrication [11]. As it is designed to achieve low profile reduction via implanting wire construct on a dielectric substrate, a miniaturized meander-shaped antenna is a viable option in this situation because the space available for its installation is constrained [12]. An antenna with a smaller size and fixed frequency operation was presented as a compact meandering slotted microstrip antenna [13]. Additionally, low bandwidth and low gain antennas present another difficulty for communication systems. Researchers have put forth a variety of methods for improving gain, BW and efficiency, with acceptable radiation characteristics utilizing several antennas with complicated shapes. The single frequency and small bandwidth of a microstrip antenna are two significant drawbacks. To address this problem, a tuning stub resembling a fork is attached to the microstrip slotted antenna [14]. On a 1.6 mm thick FR-4 substrate, a capacitive load (C-load) was applied to increase peak gain with a fractional BW of 7.23% and improve impedance matching, which represents a distinguished performance enhancement approach [15]. To increase the fractional bandwidth, embedded metamaterials were also used [16,17]. However, applying a parasitic patch to the antenna is a useful technique for increasing the BW and gain. The bandwidth and gain are increased by approximately 3.3 dB [18] when the parasitic patch is situated close to the feed patch. Mobile phones for 2.4 GHz have parasitic patches installed with an inverted F-antenna, and the impedance bandwidth is 90 MHz [19]. Using a parasitic element, which acts as a director in the low working range between 1.6 and 3.45 GHz, impedance matching was enhanced [20]. The circular disc monopole antenna was also given shaped ground in order to match its 50-ohm impedance [21]. When parasitic elements are applied to the microstrip antenna at frequencies of 2.99–3.10 GHz and 2.1–11.1 GHz, respectively, the impedance bandwidth likewise increases from 4.3% to 6% and 136% [22,23].

For the designing of compact antennas for 2.4 GHz ISM band applications, fractal antennas are one of best available techniques, as explained in [24,25]. The use of truncated corners is another well-studied technique to achieve compact antenna for microwave, as proposed in [26,27]. The open-ended stub loading technique is also widely studied, as explained in [28,29]. To obtain a satisfactory impedance fractional bandwidth of 2.4 GHz, a variety of different-shaped antennas of various sizes were proposed and measured [24–27]. For biotelemetry in biomedical investigative systems, a small, strong, and flexible body-worn antenna was presented in [30]. In order to ensure that the antenna is of the ideal size and works at a lower frequency band of interest, the fractal-based design lengthened the current flow. WMTS and ISM bands are simultaneously covered using the antenna's dual-band operation (1.38–1.8 GHz and 2.25–4.88 GHz). However, [31] presents a dual-band antenna for on- and off-body communications in the ISM frequencies bands of 2.45 GHz and 5.8 GHz, with silver material combined onto a stretchable polydimethylsiloxane (PDMS) substrate, which is more useful for wearable applications. In [32], a compact antenna-based PDMS with an overall size of 14×33 mm^2 was introduced with a 15% broadband offering and centered at 2.45 GHz. In contrast, a conformal antenna with electronic tuning capability was presented in [33]; it involves a 40 mm bending radius using a PDMS substrate, with 64% being the achieved efficiency in the broadside mode.

This paper reports a well-modified L-shaped compact antenna for 2.4 GHz ISM band IoT applications. The simulation was conducted using the Computer Simulation Technology (CST) Microwave Studio simulator. For experimental measurements, the antenna was constructed on a Rogers 5880 printed circuit board. A straightforward L-shaped strip line was attached to the feed SMA connector in this design, and integrated with an etching slot built on the backside to obtain sufficient gain and bandwidth. It is demonstrated that a ground shape can provide the gain at a constant value while improving both bandwidth and efficiency results. Additionally, an experiment to assess the performance of the antenna is provided, and the findings show that the results are in good agreement with the simulation.

2. Antenna Design

The proposed L-shaped antenna (Figure 1) was constructed on a Rogers 5880 substrate, with $\varepsilon_r = 2.2$ permittivity, thickness of 1.57 mm, and loss tangent = 0.0009. The antenna measured 28 mm $\times$ 21 mm in dimensions. The microstrip patch was two perpendicular lines forming an inverted L-shape to produce the main radiator. The proposed main radiator was designed as a simple microstrip strip line patch, which was directly linked to the port feeding. It was followed by a perpendicular line that formed an L-shape, which was modified and optimized within several steps to find the optimal band of interest at 2.4 GHz, as demonstrated in Figure 1. The proposed antenna's impedance was 51 ohms, whereas the feed line was linked to matching a 50-ohm impedance. In order to find the impedance-matching bandwidth, a rectangular slot was also created in the ground plane's middle section, not far from the feed line. Using parametric study for various values, the impact of the L shape and ground slot was clarified. The proposed antenna was created and measured to confirm its validity. Figure 2 shows the fabricated antenna.

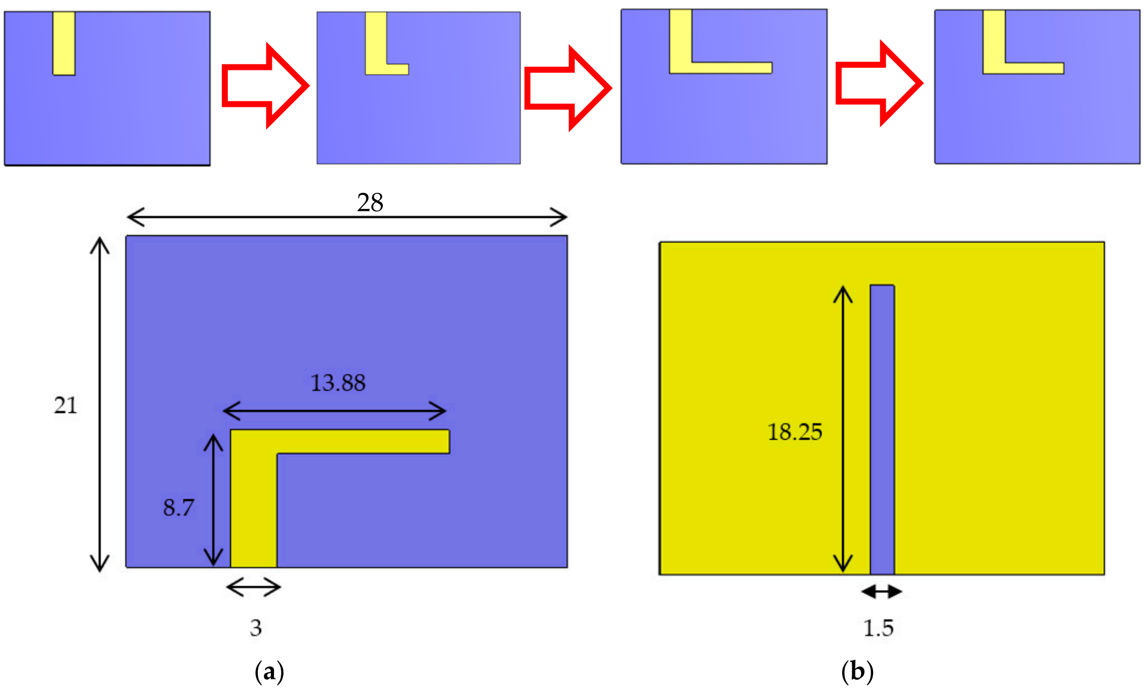
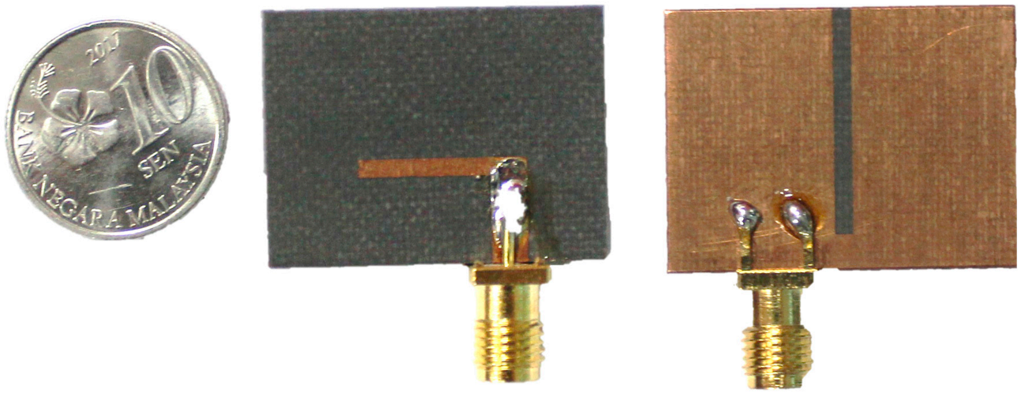


Figure 1. Antenna topology: (**a**) front patch, (**b**) back side ground plane. Unit: mm.



(a) **(b)**

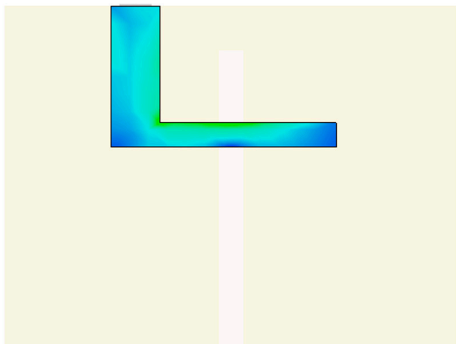
Figure 2. Fabricated prototype: (**a**) patch, (**b**) backside ground.

3. Parametric Study Working Principles

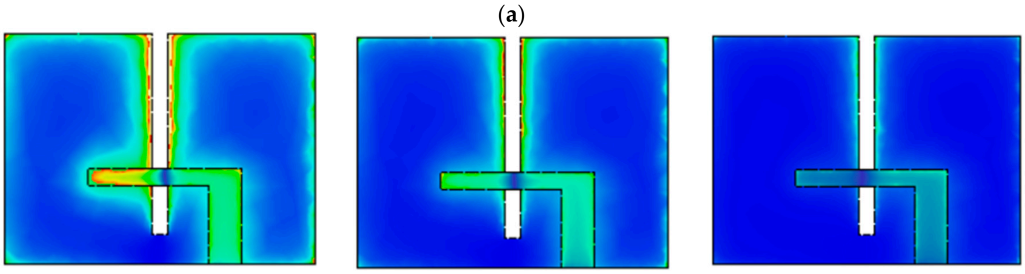
The structure's key parameters are illustrated in later parts to show how they affect its functionality. The proposed antenna performance depends mainly on the dimensions of the L-shaped strip, as well as the height and width of the aperture at the ground plane.

3.1. Working Principles

The simulated current distribution is examined and studied in order to shed light on the characteristics and operating principles of the proposed antenna. Figure 3a displays the antenna's current distribution at 2.4 GHz. The radiating element of the proposed antenna demonstrates that the principal radiator is the region of the external edges of the L radiating element, where the majority of the current distribution is focused. However, the patch's high current distribution on the upper side of the L shape helps the antenna's resonance through shifting it at 2.4 GHz, while the antenna's expanded top portion of the L shape has an impact on its gain due to the appearance of the extraordinary current on the upper part.



(**a**)



(**b**) (**c**) (**d**)

Figure 3. Simulated of optimized antenna current distribution at frequency (**a**) 2.4 GHz (**b**) 2.44 GHz; (**c**) 2.48 GHz; (**d**) 2.58 GHz.

Figure 3b displays the surface current distribution in the upper antenna arm at the resonant frequency of 2.44 GHz, whereas the whole structure exhibits single-order resonance properties. The L shape with a backside slot cut in the ground perturbs the current distribution, creating resonance at 2.4 GHz. However, the antenna's operation in the slightly shifted frequencies of 2.48 GHz and 2.58 GHz can be attributed to two distinct minima, which are seen for the current for both cases: one at the end of the arm and the other at several points in the upper edge. In contrast, low current concentration via the L shape is achieved in the case of non-resonating bands, as seen in Figure 3c,d.

3.2. Aperture's Length (L) and Width (W)

The aperture slot length (L) and width (W) affect the resonance frequency bandwidth significantly, as illustrated in Figure 4.

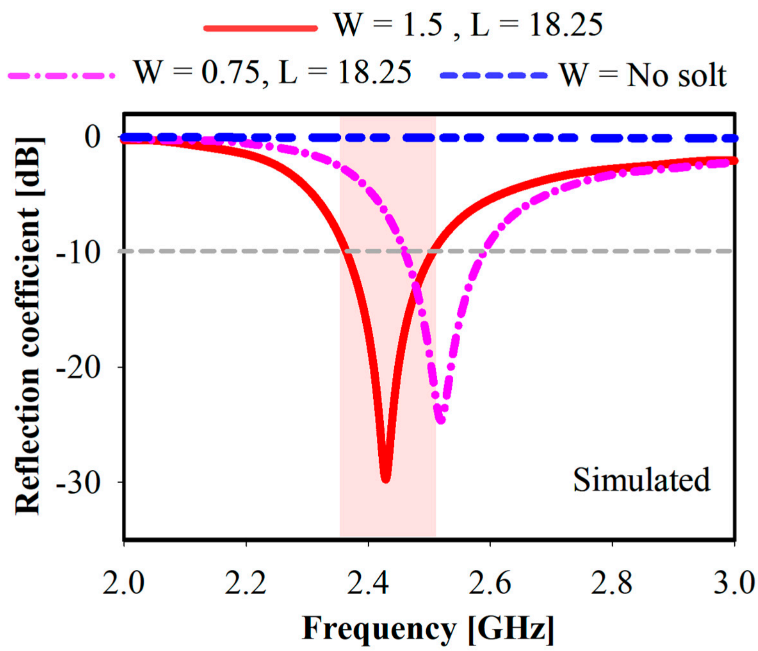


Figure 4. Simulated reflection coefficients for different antenna lengths (L).

Narrower W with 0.75 mm shifts the bandwidth towards a higher frequency. Both L and W are varied together, whereas the resonance at 2.4 GHz totally disappears in the case of no slot. However, slot L = 18.25 mm and W= 1.5 mm are the optimal dimensions for the achieved bandwidth.

3.3. Patch's Length (LP) and Width (WP)

It is observed that the increment of the patch's line length (LP) leads to enlarged bandwidths at 2.4 GHz. Figure 5 demonstrates the simulated reflection coefficient of the proposed antenna. LP is kept above −10 dB in the case of sort LP at 8 mm, whereas the resonance at 2.4 GHz starts to disappear. Furthermore, no resonance can be seen when LP = 3 mm. The optimum value for the LP is 18.25, which is chosen to attain the targeted operating frequency band. However, a very narrow bandwidth is observed when the patch's width WP = 1 mm and the length remains constant at 18.25 mm, as illustrated in Figure 6. This resonance will be continuously reduced if the WP decreases accordingly.

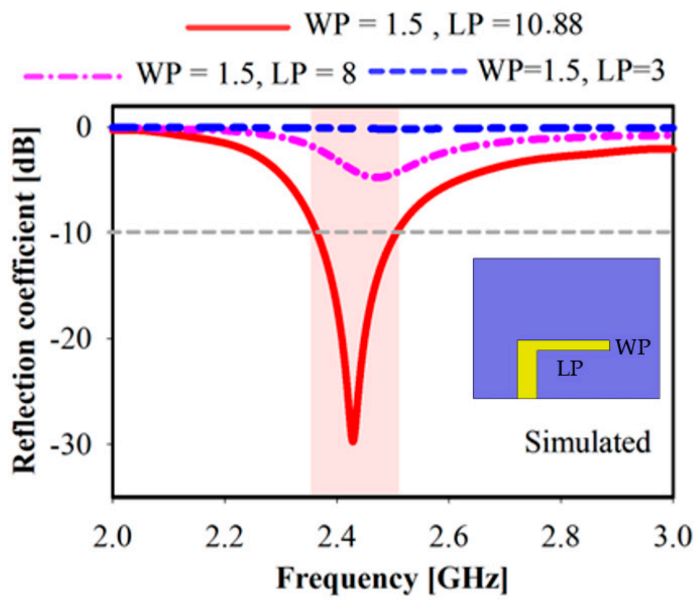


Figure 5. Simulated different patch's length reflection coefficient.

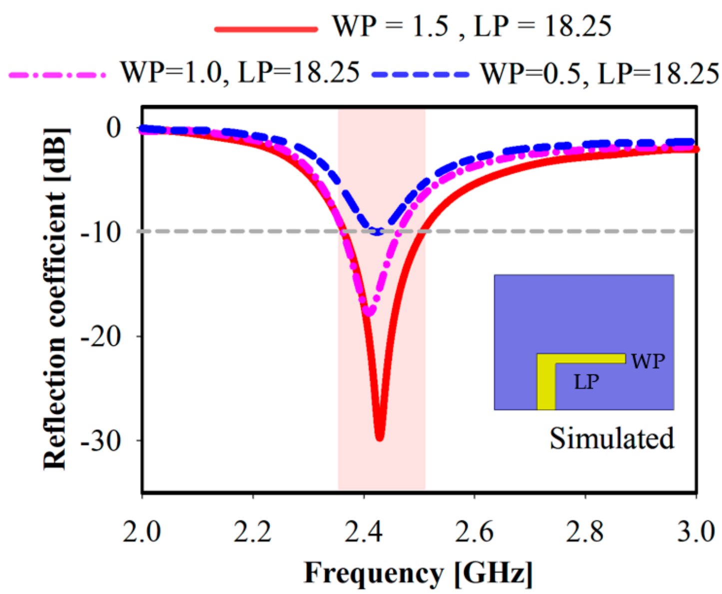


Figure 6. Simulated different patch widths reflection coefficient.

4. Results and Discussion

To ensure the greatest performance in terms of the band of interest, bandwidth, compact size, and gain, a number of crucial characteristics of the proposed L-shaped antenna were optimized prior to the choice and manufacture of the final structure. The simulation and measurement of the final prototype's reflection coefficient are shown in Figure 7. The antenna's final optimized overall dimensions are 28 mm × 21 mm × 1.6 mm. The proposed antenna's realized bandwidth spans a minimum of 2.36 GHz and a maximum of 2.5 GHz (with a total of 145 MHz, i.e., 5.8%). Figure 8 illustrates the efficiency of the L-shaped antenna. The exhibited radiation and total efficiencies have peaks of 98% and 97%, respectively, at 2.4 GHz. In addition, the achieved gain of the proposed single antenna in the operation bandwidth is defined. The realized gain can reach up to 2.09 dBi, though it decreases slightly towards a lower frequency range, as demonstrated in Figure 8. The simulated and measured findings showed a good agreement. Furthermore, Figure 9 displays the achieved simulated gain with different widths of the slot placed on the ground plane; this figure shows the effect of that slot on achieving high realized gain on the 1.5 mm width.

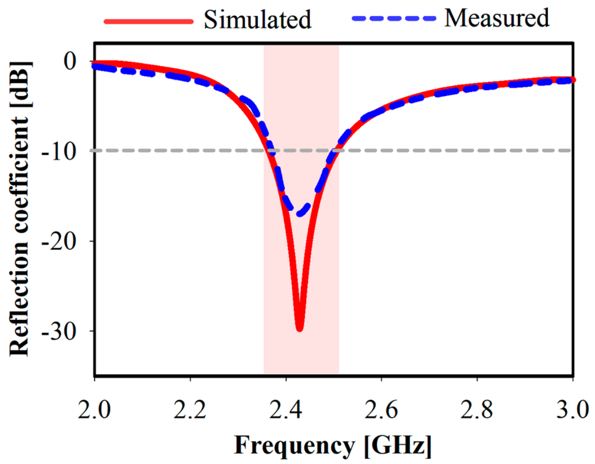


Figure 7. Simulated and measured reflection coefficient.

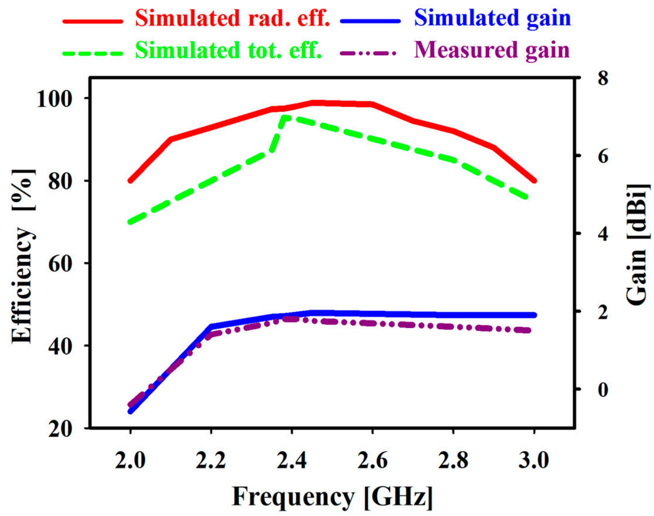


Figure 8. Simulated and measured gain, radiation efficiency, and total efficiency for proposed antenna.

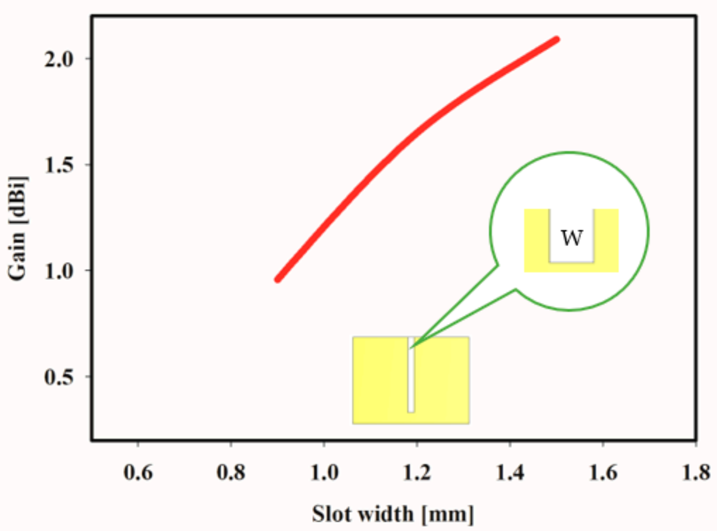


Figure 9. Simulated analysis of gain.

Figure 10 displays the simulated and measured 2.4 GHz azimuth-plane radiation patterns. The antenna radiates in the H-plane with modest amounts of cross-polarization and vertical polarization (xz-plane). The proposed antenna has a figure-of-eight radiation pattern at 2.4 GHz in the E-plane (yz-plane). Figure 11 shows the S11 reflection coefficient and radiation pattern measurement setup for the proposed antenna.

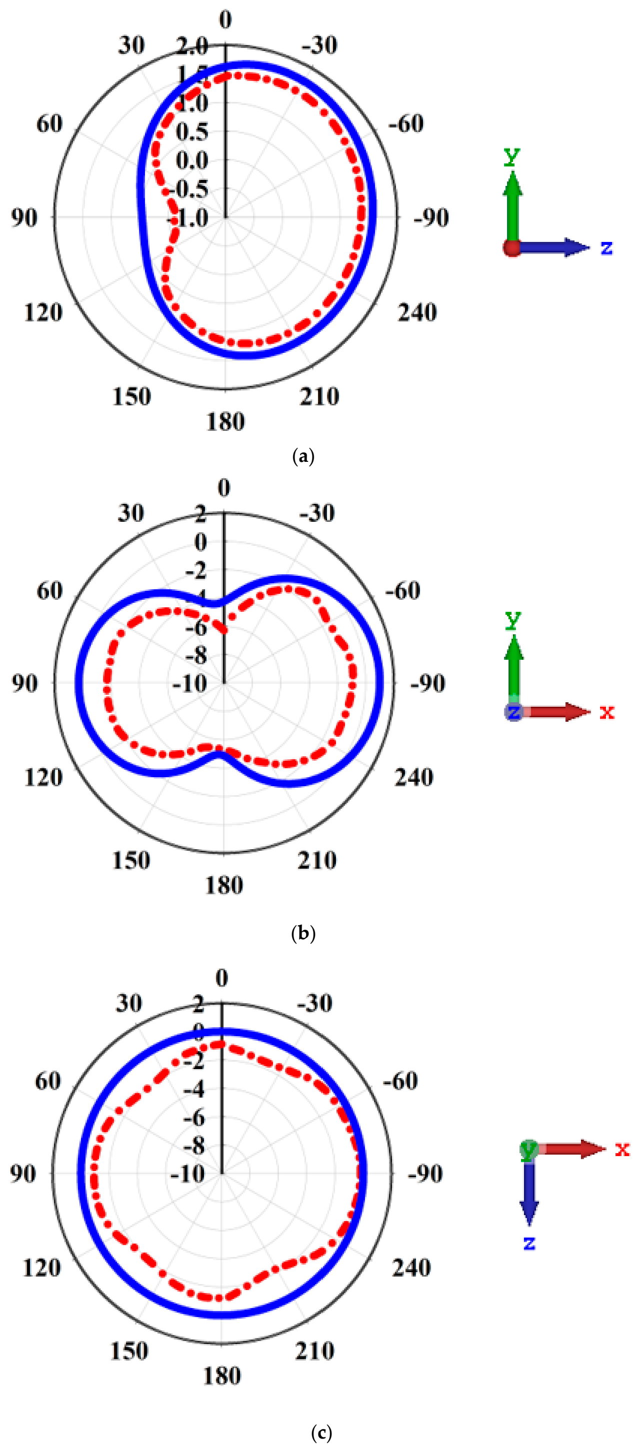
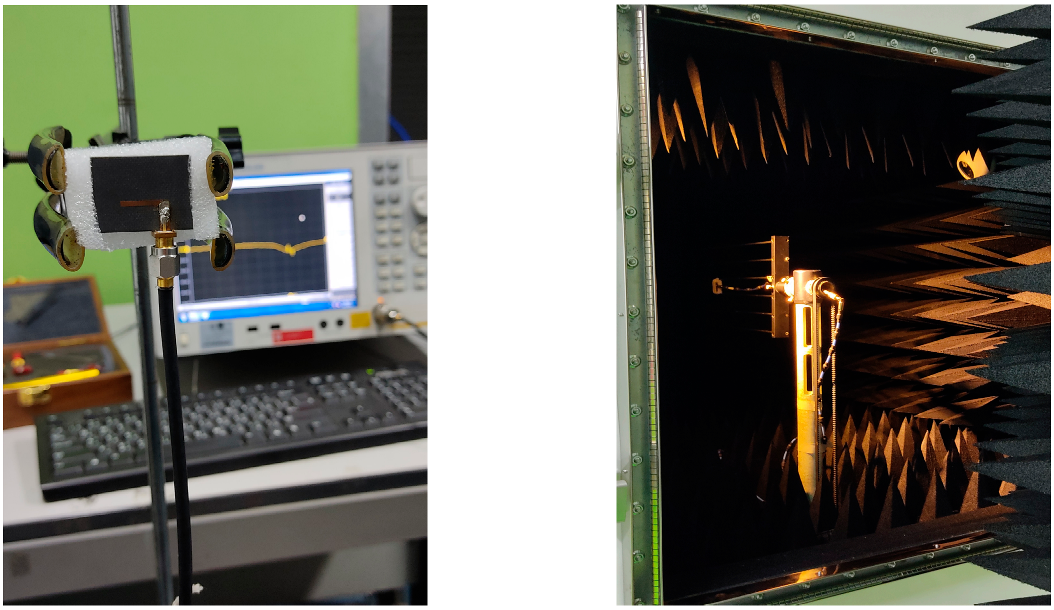


Figure 10. Two-dimensional simulated and measured radiation patterns at 2.4 GHz for planes: (**a**) YZ (Ø = 90°), (**b**) XY (θ = 90°), (**c**) XZ (Ø = 0°).



(**a**) (**b**)

Figure 11. Measurement setup: (**a**) S11, (**b**) radiation pattern.

Figure 12 depicts the simulated face-to-face group delay (GD) of the suggested compact antenna. Over the frequency range, it is almost homogeneous with little change (1.3 ns). As a result, it is clear that there was no signal distortion between the transmitting and receiving antenna systems. Additionally, the transfer function (TF) in Figure 10 with the transmission coefficient S21 exhibits reduced distortion. As a result, this antenna is suited to use in IoT and short-range communications applications because of the realized TF and flat GD over the frequency range.

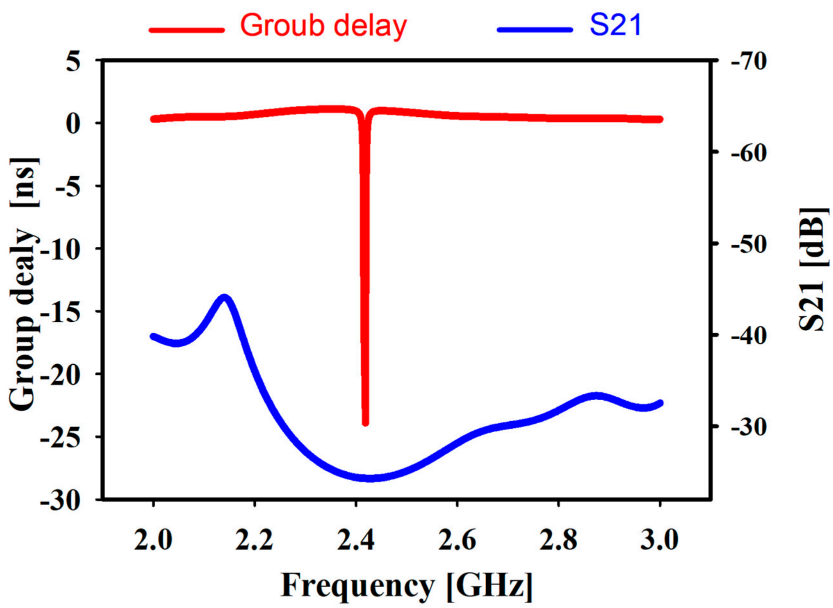


Figure 12. Face-to-face position response of group is delayed.

The suggested antenna is contrasted with the current microstrip antenna at 2.4 GHz in Table 1. A variety of 2.4 GHz antenna topologies were reported by researchers, together with parametric and experimental results for various applications. The comparison demonstrates that, in contrast to all of the other designs, the proposed compact antenna has a higher gain. The comparison table makes clear that existing antenna dimensions are typically bigger than those of the suggested antenna. Furthermore, the performance of the proposed antenna at 2.4 GHz is better than others, and is a workable solution for 2.4 GHz IoT.

Table 1. Performance comparison for state of proposed L-shaped antenna at 2.4 GHz.

Year	Ref.	Antenna Shape	Antenna Size	Fractional BW (%)	Rad. Eff. (%)	Gain (dB)	Applications
2014	[11]	Meander line	32.00×01.60	7.60	-	0.50	* NS
2017	[34]	Spiral slot	12.45×13.05	7.50	-	1.33	* NS
2018	[35]	Uniplanar	10.00×19.00	8.00	-	1.20	2.5 GHz applications
2018	[36]	Bowtie antenna	29.00×13.70	-	89	1.47	Wearable application
2019	[37]	Meander line	40.00×10.00	12.5	79	1.34	IoT
2020	[38]	Slotted SIW	120.0×395.4	2.10	-	4.80	WLAN
2021	[39]	Slot antenna	105.0×85.00	3.20	-	4.00	IoT
2022	[40]	Cage antenna	49.00×49.00	3.20	93	3.00	WLAN
2023	This study	L-shaped	28.00×21.00	5.80	98	2.09	IoT

* NS: not specific.

5. Application Scenarios

The suggested antenna can be used for various indoor communications applications, including smart homes, airports, malls, etc. These suggested uses are viable because the proposed antenna covers the significant IoT band of microwave bands. The following subsection contains an explanation of an application scenario.

Indoor Localization Systems

Future smart homes, airports, and retail centres will use microwave and mm-wave bands for indoor connectivity to facilitate multi-system wireless communication networks, whereas microwave frequency bands will offer long-range telecommunications with average speeds that link an enormous number of multi-media gadgets and IoT devices [41]. The proposed antenna will be used to collect the received signal strength (RSS) in a specific indoor scenario within different positions of the mobile station subscriber, highly identifying its location without using a global position satellite (GPS). This technique analyzes variations in RSS between one transmitter, known as a single base station (SBS), and a huge number of subscriber mobile station receivers. Therefore, it will be evaluated based on the algorithm proposed in [42,43] to estimate the unknown mobile station receiver positions with the SBS.

6. Conclusions

Nowadays, one of the benefits of IoT applications is the use of antenna terminals as wireless sensor technologies. In this study, a prospective solution to be utilized in IoT-based applications is introduced. The proposed compact antenna is modified and constructed as an L-shaped antenna for the ISM at the 2.4 GHz frequency band. The influence of the straightforward L-shape patch, along with an etching rectangular backside slot in the ground plane, was examined numerically and verified using measurements. The obtained results showed that the antenna had an excellent radiation efficiency of 98% and simulated attained gain up to 2.09 dBi, which are well-thought-out as special considerations compared to other conventional antennas. The proposed antenna is a viable candidate for wireless fourth-generation 4G and IoT, especially in an indoor development scenario for smart offices/homes. Upcoming work will apply the proposed antenna in radio frequency (RF) modules for IoT sensors as a transmitter for indoor localization estimation using only one base station.

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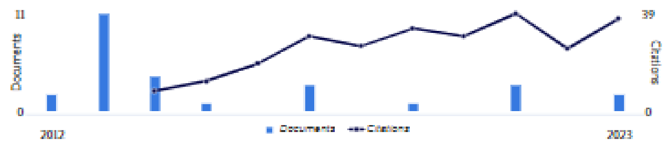

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