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Dual-band GPS/LoRa antenna for internet of thing applications

Muhammad Sani Yahya[1,2], Socheatra Soeung[1], Francis Emmanuel Chinda[1], Umar Musa[3,4], Zainab Yunusa[5]
[1]Department of Electrical and Electronic Engineering, Universiti Teknologi PETRONAS, Perak, Malaysia
[2]Department of Electrical and Electronics Engineering, Abubakar Tafawa Balewa University Bauchi, Nigeria
[3]Faculty of Electrical and Electronic Engineering, University Tun Hussein Onn, Johor, Malaysia
[4]Department of Electrical Engineering, Faculty of Engineering, Bayero University Kano, Kano, Nigeria
[5]Department of Electrical Engineering, University of Hafr Al Batin, Al Jamiah, Saudi Arabia

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ABSTRACT

This paper presents the design and characterization of a compact dual-band microstrip antenna for GPS and long range (LoRa) internet of thing (IoT) applications. The antenna operates at 868 MHz and 1.57 GHz and has a gain of 3.35 dBi and 5.08 dBi, respectively. The antenna design is optimized using CST microwave studio software (MWS®), and both simulation and measurement results are in close agreement. The antenna features a directional E-plane and omnidirectional H-plane radiation pattern in each band of operation. The proposed antenna's compact size and dual-band capability make it suitable for IoT applications that require GPS and LoRa communication in a small form factor. The results presented in this paper demonstrate the feasibility and effectiveness of the proposed antenna design.

Corresponding Author:

Muhammad Sani Yahya
Department of Electrical and Electronic Engineering, Universiti Teknologi PETRONAS
Persiaran UTP, 32610 Seri Iskandar, Perak, Malaysia
Email: muhammad_22000359@utp.edu.my

1. INTRODUCTION

The term "internet of things" (IoT) appeared in Kevin Ashton's work in 1999 to describe internet connected smart objects [1]. IoT can also be defined as a network of "smart" objects or "smart" devices which has an embedded or external mounted sensors, actuators, in-built wireless connectivity, or any other device by means of which data can be collected and transferred to the network in the cloud. Nowadays, there is an unprecedented connectivity of large number of smart physical objects as parts of IoT realization [2]. The IoT is rapidly expanding beyond the realm of machine-to-machine communication to include human-to human, and human-to-machine communications [3]. IoT contributes significantly to improve our standards of living in a variety of ways, such as in smart farming, smart agriculture, smart homes, smart transportation and logistics, and industrial automation.

In recent years, the number of IoT devices has significantly increased. It is anticipated that by 2022, about 20.4 billion devices would emerge and this will further escalate to 27 billion by the year 2024. By 2025, over 75 billion of connected devices across a variety of fields of interest would be available thanks to the IoT concept. According to estimations provided by the McKinsey Global Institute, the IoT might have a $6.2 trillion economic impact on the world economy by 2025 [4], [5].

Wireless communication technologies has in large part facilitated communication between IoT devices and cloud services. Bluetooth low energy (BLE), Wi-Fi, radio frequency identification (RFID), bluetooth, long term evolution (LTE), IPv6 over low-power wireless personal area networks (6LoPWAN), near field communications (NFC), LoRa, and Sigfox are some of the wireless communication technologies used in IoT [6].

IoT devices are often powered by stand-alone batteries since they are typically installed in locations where it is very difficult to get electricity. Therefore, it is crucial to consider the battery's lifespan and power usage while designing IoT devices. In a similar vein, the majority of IoT devices are installed at long distance from one another; hence, it is vital to use network with wide signal coverage in order to have efficient communication between these devices and the base station [7], [8]. Therefore, in IoT, it is crucial that devices should communicate with one another in a reliable and energy-efficient manner.

In IoT communications, two categories of low power networks are used: short-range and long-range. RFID, 6LoWPAN, BLE, and NFC. All fall under the category of short-range low-power technologies. Low-power wide area network (LPWAN) is designed to offer low cost, long-range, and low-power communications for IoT devices. Examples of LPWAN technologies include SigFox, narrow band internet of things (NB-IoT), and long range (LoRa). LPWAN technologies are characterized by low data rate, but that is not a problem considering the fact that in IoT communications, sensor nodes are only required to transmit low data packets such as parameters of GPS location, humidity, and temperature [9], [10].

NB-IoT and LoRa are two of the current market leaders of LPWAN technologies. The former operates in the licensed frequency bands and operates on the global system for mobile communication (GSM) networks and long-term evolution (LTE). It was developed by the third generation partnership project (3GPP). It uses QPSK, or quadrature phase shift keying, for modulation. The latter was first developed as a start-up initiative in Grenoble, France, under the name of Cycleo. Only three years later, it was acquired by the Semtech corporation in the United States, and then LoRa-Alliance standardized it in 2015. LoRa operates in an industrial scientific and medical (ISM) unlicensed frequency band below 1 GHz. It uses chirp spread spectrum (CSS) technique of modulation which enables it to achieve long link budget with low power consumption [10], [11].

Long range wide area network (LoRaWAN) is a media access control protocol (MAC) designed for LoRa based wide area networks and IoT applications to achieve to achieve long signal transmission up to range of kilometres [12]. As a low power and long-range wireless communication technology, LoRa is mostly powered by a battery which can last up to ten (10) years without replacement. It is now being used in a wide variety of applications, including home automation systems, smart healthcare, smart cities, industrial control, environmental monitoring, logistics, and intelligent supply chains and smart farming systems. These characteristics makes LoRa one of the key enablers of IoT [13].

The operating frequencies of LoRa in the ISM band varies according to regions globally. This is due to regulatory requirements. For example, 433 MHz and 868 MHz are used by most EU countries, 915 MHz for America and 923 MHz in some Asian countries [14]. It can be observed that LoRa operates in sub 1-GHz bands. Due to the longer wavelength of signals at these frequencies (below 1 GHz), there is less effect of multipath fading and attenuation of signals by trees, concrete walls. Similarly, there is less congestion in the sub 1 GHz band in contrast to other bands employed by the famous wireless technologies, such as ZigBee, and Wi-Fi [15].

The key factors required for the successful operation of any wireless system are robust and sophisticated communication protocols, as well as an efficient hardware. An antenna is one of these crucial hardwares that are used to transmit and receive signals [16]. It is the backbone of any wireless communication. Since LoRa operates at frequencies below 1 GHz and considering the requirements of emerging IoT devices of compactness and portability, designing a compact antenna that can be integrated with such devices is a great technical challenge [17], [18].

Microstrip patch antenna (MPA) have received great attention due to its characteristics of mechanical robustness, light weight, ease of design, ease of manufacture using the modern technology of printed-circuits and ease of integration with both planar and nonplanar surfaces [19]–[22]. As a result, it is the best option to be employed in designing an antenna for LoRa IoT communications. In the last decade, several MPA were reported for LoRa applications [23], [24]. Among these literatures, very few considered the design of an MPA for GPS/LoRa applications.

An IoT terminal with a dimension 300 × 30 × 0.8 mm^3 deigned to support three antennas operating at four frequency bands was presented in [25]. The terminal comprises: dual-band global navigation satellite system (GNSS) antenna at 1.21 GHz and 1.57 GHz for the L1 and L2 Galileo frequencies respectively, LoRa

868 MHz and LoRa 2.4 GHz antenna. The realized maximum gain of the GNSS antenna was 3.05 dBi for both L1 and L2 frequencies, 4.17 dBi at 2.4 GHz and 3.36 dBi at 868 MHz. This antenna has occupied a large space, hence not suitable to be used with compact geolocation IoT devices.

Similarly, a compact folded inverted F antenna (FIFA) having dual resonance was presented in [24]. The antenna was proposed to be included in a miniature geolocation device to cover LoRa band (868 MHz) and global positioning system (GPS) band (1.57 GHz) simultaneously. It has a dimension of 13 × 25 mm^2 and it was placed on the topmost section of a 40 × 25 mm^2 printed circuit board, whose primary portion was reserved for electronic circuitries required by the geolocation device. The antenna has achieved an efficiency of -6 dB and -3 dB in the LoRa and GPS bands respectively. It is obvious that the antenna's miniaturization was at the expense of its radiation efficiency, however, it should be noted that, the antenna's radiation efficiency is an essential parameter and must be improved for good performance.

This paper presents a compact dual-band antenna intended to cover both GPS 1.57 GHz band and LoRa 868 MHz band for geolocation applications in a tracking device. The antenna will use the GPS 1.57 MHz to acquire geolocation information from GNSS and transmit this information through LoRa transceiver at 868 MHz.

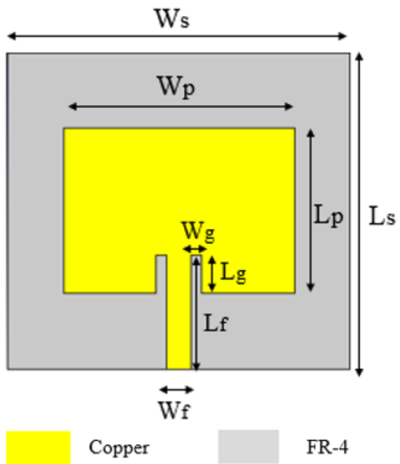
The organization of the remaining parts of this work is as follows: section 2 delves into the structure and design of a dual-band antenna that is proposed. Following that, section 3 discusses the simulation and fabrication results of the antenna in relation to its return loss (S_{11}), radiation pattern, current distribution, and gain. Lastly, section 4 serves as a conclusion.

2. ANTENNA DESIGN AND GEOMETRY

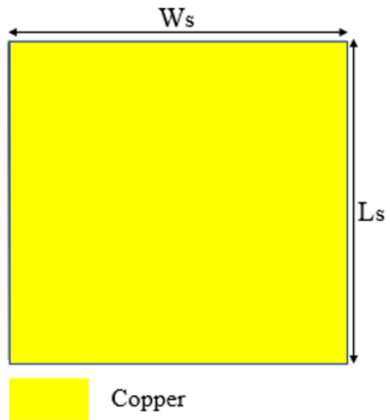
2.1. Single band antenna design

A full ground plane rectangular patch antenna as shown in Figures 1(a) and (b) is designed on an FR-4 substrate. The substrate has a height (t_s) of 1.6 mm, loss tangent tanδ of 0.019 and permittivity (ϵ_r) of 4.4. The patch has a width and length defined as W_p and L_p respectively as depicted in in Figure 1(a). Among the most used conductor materials for patch antenna design are copper, silver and gold.

The conductivity of silver is higher than that of copper and gold. Similarly, it is superior to other metals, however, copper is much cheaper in cost and harder than silver and gold. Therefore, copper is normally used as a conductor in patch antennas. A copper conductor with a thickness of 0.035 mm is used for both the patch and the ground plane of the proposed antenna. Similarly, an inset feed with length L_f and width W_f is used to excite the antenna. For the purpose of achieving effective impedance matching between the feedline and the patch without the use of any extra matching element, an inset gap with length L_g and width W_g is cut as shown in Figure 1. The dimensions and parameters of the antenna at 1.57 GHz are calculated from the standard technique described by [26]. The calculated and optimized values of the antenna are given in Table 1.



(a)



(b)

Figure 1. Structure of the proposed antenna; (a) front and (b) back

Table 1. Parameters of the proposed antenna

Description	Parameter	Calculated (mm)	Optimized (mm)
Length of substrate	Ls	85	65
Width of substrate	Ws	65	62
Length of patch	W	58.14	55.15
Width of patch	Lp	45.28	46
Width of feed	Wf	3.06	3.06
Length of feed	Lf	19.86	9.5
Width of inset	Wg	3.5	3.06
Length of inset	Lg	8	7
Thickness of substrate	ts	1.6	1.6
Thickness of patch	tp	0.035	0.035

3. RESULTS AND ANALYSIS

3.1. Return loss

The S_{11} of the antenna operating at 1.57 GHz for GPS signal reception is illustrated in Figure 2. The antenna has its resonance frequency at 1.5744 GHz and has achieved an impedance bandwidth <-10 dB of 47 MHz from 1.55 to 1.597 GHz. Similarly, the VSWR of the proposed antenna is illustrated in Figure 3. It is obvious that within the operating bandwidth of the antenna, the VSWR is <2. This indicates a good matching between the feedline and the patch element.

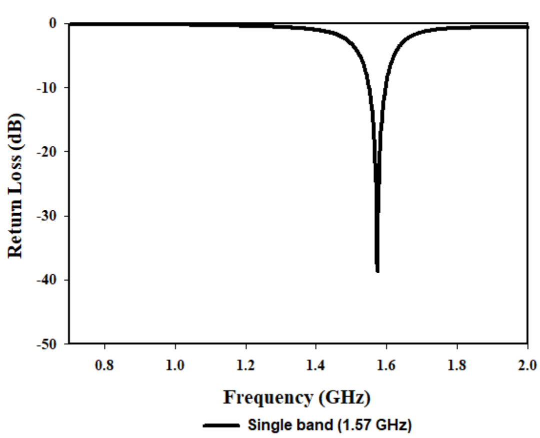


Figure 2. Return loss of the proposed GPS antenna at 1.57 GHz

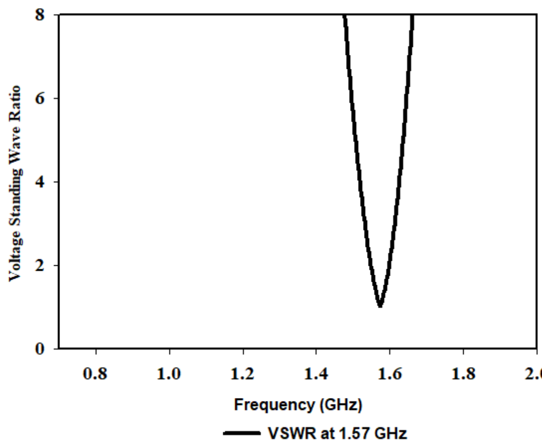


Figure 3. VSWR of the antenna at 1.57 GHz for GPS application

3.2. Dual-band antenna for LoRa and GPS applications

The proposed antenna is intended to operate at 1.57 GHz to be used in a tracking device to acquire geolocation information from GNSS and transmit this information through LoRa transceiver at 868 MHz. To achieve dual band in an MPA, different techniques can be used. These include stacking, parasitic patches, shorting pins, shorting walls and active devices. In this work, a simple and non-complex technique i.e., parasitic patch is applied. Patch 2 is added at a distance d_1=5 mm above the main radiating patch (patch 1) to create additional resonance at 868 MHz for LoRa application as shown in Figure 4.

A parameter sweep is performed on W_{p2} and L_{p2} to obtain the optimum values for 868 MHz. Figures 5 and 6 show the parameter sweep carried on the effect of varying the width and length (W_{p2} and L_{p2}) of patch 2 respectively. It can be seen that; 868 MHz is obtained when W_{p2} = 53 mm and L_{p2} = 3 mm. The S_{11} of the dual-band antenna having resonance at 868 MHz and 1.57 GHz is depicted in Figure 7. Similarly, its VSWR is depicted in Figure 8. It is observed that at both 868 MHz and 1.57 GHz the VSWR is <2. This shows good matching between the feedline and the radiating patches.

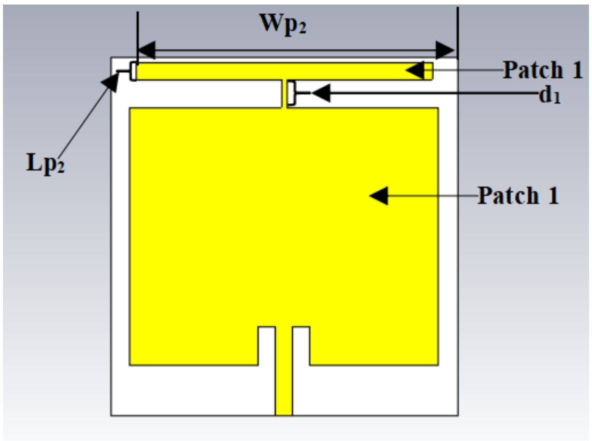


Figure 4. Proposed dual-band antenna geometry

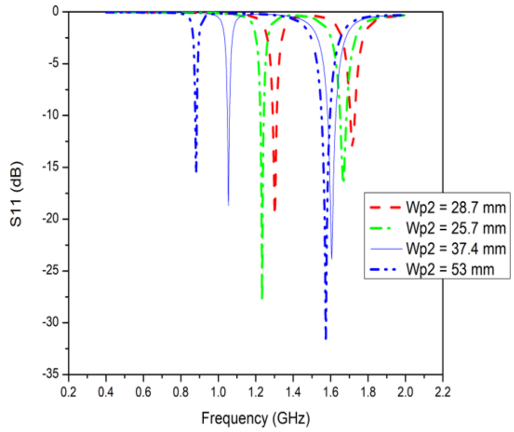


Figure 5. Variation of W_{p2} and its effects on the resonance frequency of the antenna

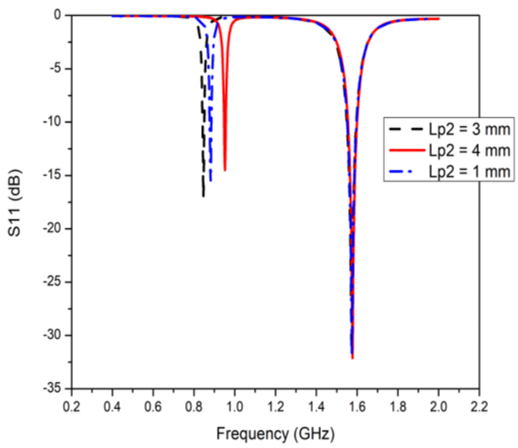


Figure 6. Variation of L_{p2} and its effects on the resonance frequency of the antenna

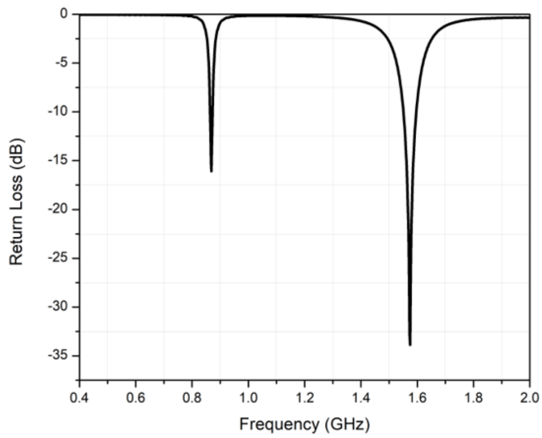


Figure 7. Return loss of the dual-band antenna

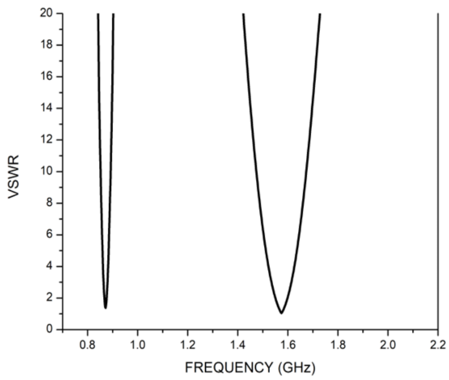


Figure 8. VSWR of the dual-band antenna

3.3. Radiation pattern

The radiation pattern of the proposed antenna analyzed in both E and H-planes are presented in Figure 9. The plot in Figures 9(a) and (c) clearly indicates that the antenna has an E-plane directional radiation pattern, which is advantageous for GPS/LoRa application where the signal needs to be concentrated in a particular direction. On the other hand, the plot in Figures 9(b) and (d) shows an omnidirectional pattern in the H-plane, which is expected. This unique feature of the antenna makes it a suitable candidate for GPS/LoRa application where both directional and omnidirectional radiation patterns are required.

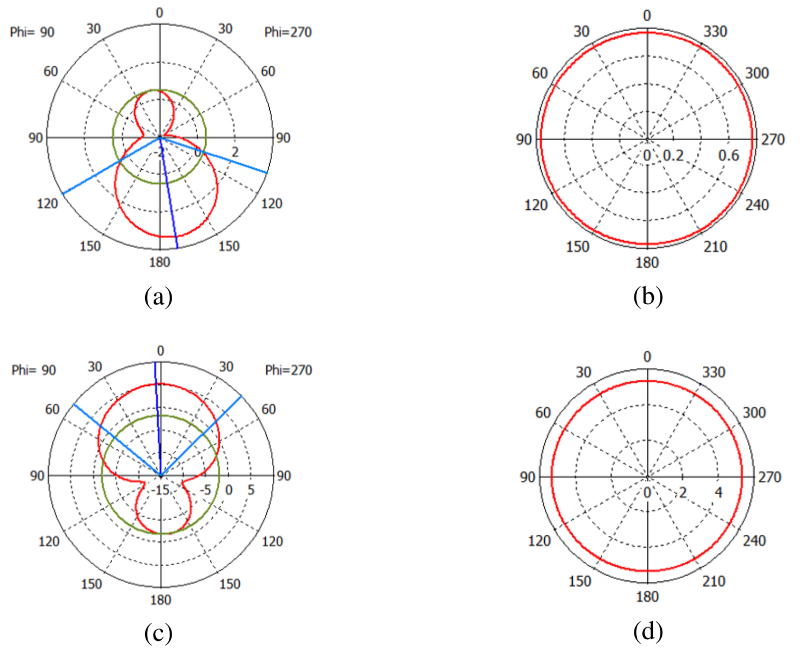


Figure 9. Radiation pattern; (a) E-plane (868 MHz), (b) H-plane (868 MHz), (c) E-plane (1.57 GHz), and (d) H-plane (1.57 GHz)

3.4. Gain

The antenna gain is an important parameter that describes the ability of an antenna to focus energy in a particular direction. As shown in Figure 10, the gain of the dual-band antenna for GPS/LoRa application has been evaluated at two different frequencies, 868 MHz and 1.57 GHz. The antenna has achieved a gain of 3.35 dBi at 868 MHz and 5.08 dBi at 1.57 GHz. The obtained results demonstrate that the proposed antenna can provide good gain at both frequency bands, which makes it a suitable choice for applications that require reliable communication at these frequencies.

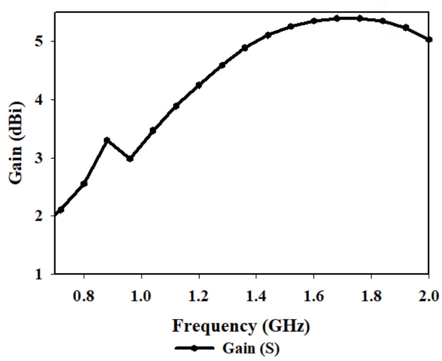


Figure 10. VSWR of the dual-band antenna

3.5. Current distribution

The current distribution of the single and dual-band patch antenna are shown in Figure 11. It is observed in Figure 11(a) that the resonance of 1.57 GHz is provided mainly by the edges of the patch. Similarly, Figure 11(b) shows the current distribution of the dual-band antenna at 868 MHz and 1.57 GHz. It is evident that patch 2 provides the resonance for the 868 MHz.

The prototype of the proposed dual-band antenna is shown in Figure 12. The simulated and measured S_{11} of the antenna are compared in Figure 13. It is observed that both the measured and simulated results are in agreement. A comparison is made in Table 2 among some recently reported literatures and the proposed dual-band antenna. It is obvious that the proposed antenna is not only compact with a dimension of 65 × 62 × 1.6 mm^3 but has comparatively high directivity in each of its dual-band. Therefore, it will be a good candidate for IoT applications in which miniaturization of devices is required.

(a) (b)

Figure 11. Current distribution; (a) 1.57 GHz and (b) 868 MHz

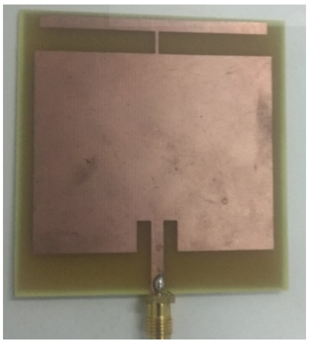


Figure 12. Prototype of the antenna

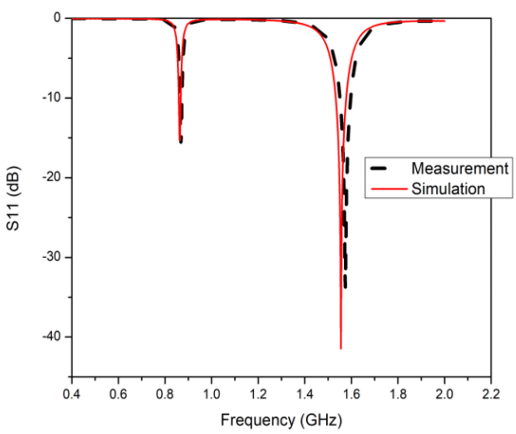


Figure 13. Comparison of simulated and measured S_{11} of the dual-band antenna

Table 2. Parameters of the proposed antenna

Ref.	Year	No. of band (s)	Frequency (MHz)	Gain	Substrate	Dielectric	Size (mm^2)
[23]	2021	1	868	2.11	FR-4	4.3	120 × 70
			868	3.36			
			1210	3.05			
			1570	3.05			
[25]	2021	4	2400	4.17	FR-4	4.3	300×30
			868				
			1170				
[24]	2016	3	1620	NA	FR-4	NA	40×25
			868	3.35			
This work		2	1570	5.08	FR-4	4.4	65×62

4. CONCLUSION

This paper has presented a compact dual-band antenna for GPS/LoRa applications that operates at 868 MHz and 1.57 GHz. The antenna was designed using a simple patch technique, where a second patch was added above the main radiating patch to create resonance at 868 MHz. The antenna exhibits a gain of 3.35 dBi at 868 MHz and 5.08 dBi at 1.57 GHz, with a compact size of 65 × 62 × 1.6 mm^3. This makes it an ideal choice for IoT applications that require miniaturization of devices. The antenna offers a promising solution for wireless communication systems operating at multiple frequency bands with small form factors.

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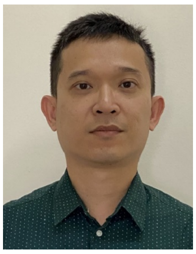
BIOGRAPHIES OF AUTHORS

Muhammad Sani Yahya received the B.Eng. degree in Electrical and Electronics Engineering from Abubakar Tafawa Balewa University Bauchi, Nigeria, in 2010, and the M.Eng. degree in Electronic and Telecommunication Engineering from the Universiti Teknologi Malaysia (UTM), in 2016. He is currently pursuing the Ph.D. degree with the Department of Electrical and Electronics Engineering, Universiti Teknologi PETRONAS (UTP), Malaysia. He is also a Lecturer with Abubakar Tafawa Balewa University Bauchi. He has published some articles in both local and international journals and has attended several local and international conferences. His research interest includes RF and microwave: antenna design and characterizations. He can be contacted at email: ymsani@atbu.edu.ng.



Socheatra Soeung (Senior Member, IEEE) received his B.Eng. (Honors) degree in Electrical and Electronics, major in Computer System Architecture from Universiti Teknologi PETRONAS, Malaysia. He completed his MSc and PhD degrees by research in RF and microwave engineering from Universiti Teknologi PETRONAS, Malaysia. He was awarded and funded as a research officer in RF microwave engineering under several Ministry of Higher Education Malaysia and industrial funding projects during his graduate study. He was involved in designing, implementing, and testing RF subsystem components and RF communication link. Currently, he works as a lecturer and a computation and communication cluster leader in Universiti Teknologi PETRONAS in electrical and electronics engineering department. He has been awarded with more than 10 fundings from Malaysian Gov't, industries, and University research collaborations. Over the years, he has been a contributor of more than 35 technical research journal and conference papers. His research interests include RF microwave filter design and synthesis for multiband, multi-mode filter on planar and cavity structures, computer-aided tuning and optimisation techniques. He is currently an IEEE, MTT member, and serve as a secretary of IEEE ED/MTT/SSC Penang Chapter, Malaysia. He can be contacted at email: socheatra.s@utp.edu.my.

Francis Emmanuel Chinda was born in 1983. He received his B.Eng. (Honors) degree in Electrical and Electronic from the prestigious University of Maiduguri, Nigeria. He completed his MSc. from the University of Nottingham, the United Kingdom in 2015 and is currently pursuing a Ph.D. at Universiti Teknologi PETRONAS in Malaysia. His research interests include RF and microwave engineering, including the design and synthesis of bandpass filters for front-end subsystem applications. He can be contacted at email: emmanuel_19000968@utp.edu.my.

Umar Musa obtained his bachelor's degree in Electrical Engineering from Bayero University Kano, Nigeria, in 2012, and M. Eng. Electronic and Telecommunication Engineering in 2016 from Universiti Teknologi Malaysia (UTM), Malaysia. He is currently a Ph.D. student in the Department of Communication Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia (UTHM). He is currently a lecturer in the Department of Electrical engineering at Bayero University Kano, Nigeria and, he is a member of the Council for the Regulation of Engineering of Nigeria since 2019. His area of research includes, but is not limited to, the design of RF and microwave devices, and active antennas measurement. He can be contacted at email: umusa.ele@buk.edu.ng.

Zainab Yunusa received the bachelor's and M.Eng. degrees in electrical engineering from Bayero University Kano, Nigeria, in 2003 and 2010, respectively, and the Ph.D. degree in sensor technology engineering from Universiti Putra Malaysia, in 2015. She has published many local and international journals and conference proceedings on the design and development of RF and microwave sensors, nanomaterials for electronic applications, and the development of microstrip patch antennas for certain applications. She is currently a Senior Lecturer with the Department of Electrical Engineering, Bayero University Kano, and also an Assistant Professor with the Department of Electrical Engineering, University of Hafr Al Batin, Saudi Arabia. She is also a Corporate Member of the Nigerian Society of Engineers and has been a member of the Council for the Regulation of Engineering of Nigeria, since 2011. Her research interests include RF and microwave devices and applications, nanomaterials for electronic applications, gas sensors, antenna design and applications. She is also a MNSE and a COREN. She can be contacted at email: zainaby@uhb.edu.sa.