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REGULAR ARTICLE

Efficient Miniaturized Patch Antenna Design for Short-Range Wireless Communications

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This paper explores the analysis of a low-profile, lightweight patch antenna fabricated on an FR-4 glass epoxy microwave substrate using a 50 Ω microstrip feed. This antenna is organized for reduced resonant frequencies, making it suitable for short-range wireless communication at 315 MHz. The antenna topology discussed a compact a meandered patch ($0.086\lambda_0 \times 0.073\lambda_0 \times 0.002\lambda_0$) resonating at 315 MHz. This antenna exhibit corresponding bandwidth (10 dB) 14.46 %. In simulation, the efficiency is measured at 89 %. Compared to a reference antenna, the design achieve significant frequency reduction of 86.48 %, indicating the potential for short-range wireless communication systems operating at 315 MHz. This communication also discusses return loss, radiation characteristics and input impedance to provide a comprehensive understanding of the antenna performance. The design details of proposed antenna topology, along with results from simulation and experiment, is outlined and discussed thoroughly. Additionally, a detail past study is included to offer a more comprehensive perspective on the antenna performance characteristics.

Keywords: Compact patch antenna, Efficient antenna, Miniaturization, Wireless communications.

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1. INTRODUCTION

The necessity to adapt antenna characteristics in response to evolving application requirements, with a particular emphasis on compactness, remains of utmost importance. This methodology is widely embraced across various disciplines, as it not only enables the seamless integration of antenna into portable devices but also enhances the overall system's performance. The increasing prominence of compact antenna within electronic devices can be attributed to the spatial constraints inherent in modern electronic designs. Notably, there is a growing focus on exploring short-range communication within the Ultra High Frequency spectrum, specifically at 315 MHz. This research has garnered significant attention due to its extensive range of applications, encompassing a wide spectrum of use cases, including remote control systems, wireless sensor technologies, alarm systems, utility metering solutions, RFID technology, consumer electronics, low-power Internet of Things (IoT) devices, industrial automation solutions, vehicular communication systems and more. The challenge of designing a compact antenna tailored to a specific frequency band, while adhering to predefined spatial limitations and simultaneously maintaining the antenna overall performance at the required standard and poses a substantial and crucial obstacle for the broader research community.

Papers [1] and [2] explore into utilizing meandered antennas, both printed and sleeved, specifically tailored for tire pressure monitoring systems, operating at reduced resonant frequencies. Additionally, studies [3] explore the use of loop and whip antennas for tire pressure monitoring applications. The development of compact, asymmetric co-planar waveguide antennas for monitoring tire pressure at a specific frequency is highlighted in [4], while [5] introduces helical antenna structures with parasitic elements applicable in tracking tire pressure. Notably, authors in [6] propose dual-band low-profile antennas for accurate tire pressure measurements, whereas [7] demonstrates a low-profile meandered slot antenna operating at 412 MHz on an FR-4 glass epoxy substrate for tire pressure monitoring. Several compact antenna designs for wireless communication have been proposed, including a miniaturized dual-band slot antenna achieving a 48.25 % reduction in resonant frequency [8], three-dimensional coupled non-planar monopole antennas [9], and miniature non-planar dipole antennas designed for short-range communication [10]. Furthermore, a complementary slot resonator antenna with an L-probe feed operating at 434 MHz [11] and an ultra-wideband antenna incorporating T and inverted T slots with a defected ground system for 5G applications [12] are also discussed.

After a comprehensive review of existing literature, it's evident that the considerable size of antennas poses challenges in seamlessly integrating them into communication systems. This observation highlights a significant research gap, especially concerning various applications. While printed antennas are widely used, our novel contribution focuses on adapting the efficient

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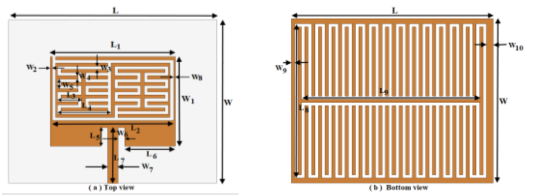
antenna for short-range wireless communication including vehicular communication application by deliberately reducing their resonant frequency. The proposed efficient antenna is well-suited for modern short-range wireless communication due to its compact size, affordability, wide bandwidth and excellent performance at 315 MHz. The following sections details the design process of the patch antenna designed for resonance at 315 MHz in Section 2. Section 3 offer results and discussion. Finally in section 4 discussed comprehensive conclusions based on our finding.

2. DESIGN OF PATCH ANTENNA FOR SHORT-RANGE WIRELESS COMMUNICATIONS

It is well known that the patch can resonate in its fundamental frequency at half the free space wave length. In comparison with conventional patch antennas [8], the current situation necessitates the development of compact antennas to prescribe new heights for short ranges wireless communication, performance for electronics industry in United States and Japan. The recommended analysis focused on designing an antenna for the application in short range wireless communication that required a specific recommended frequency, i.e, 315 MHz (±10). The antenna dimension is $0.086\lambda_0$ in length, $0.073\lambda_0$ in width and $0.002\lambda_0$ in height to make the configuration novel. Design parameters of patch antenna in millimeter unit are as follows: $L = 60$, $L_1 = 36$, $L_2 = 35$, $L_3 = 7$, $L_4 = 15.5$, $L_5 = 7.1$, $L_6 = 14.52$, $L_7 = 17.4$, $L_8 = 48$, $L_9 = 53$, $W = 51$, $W_1 = 28$, $W_2 = 0.5$, $W_3 = 1$, $W_4 = 1$, $W_5 = 3$, $W_6 = 2$, $W_7 = 3$, $W_8 = 0.5$, $W_9 = 1$, $W_{10} = 1$. The patch with ground plane is responsible to resonate the antenna at specific frequency band.



(a) (b)

Fig. 1 – Geometry of the patch antenna (a) Top view (b) Bottom view

The rectangular patch is located at the top of the mi crowave substrate, as delineated in Figure 1 (a), con-taining a meandered slot. Additionally, the bottom sur-face of the microwave substrate is also integrated with the meandered slot, as highlighted in Figure 1 (b). The 50 Ω microstrip feed line is applied to excite the patch configuration. To make the topology simple and easy to implement, we developed the meandered patch configu-ration on the top and meandered ground configuration on bottom of the microwave substrate with 1mm identi-cal slot width. The top and bottom views of fabricated prototype are represented in Figure 6 (a, b). The meas-urement configuration for the patch antenna is shown in Figure 7.

3. RESULT AND DISCUSSION

This segment contains compact antenna design for the entire United States and Japan electronics industry for short range wireless communication applications. It can be noticed in return loss characteristics in Figure 2 that the simulated frequency is 315 MHz. In comparison to the simulated resonant frequency 0.31 % fabrication errors occurred during measurement process. In the field of short-range wireless communication, operating frequencies generally range from 300 MHz to 960 MHz, with communication distances varying between 3 and 100 meters between the transmitter and receiver. In the context of short-range wireless communication, the most commonly used resonant frequency in the United States and Japan is standardized at 315 MHz (±10), preferably in the electronics and communication technology. The percentage of reduction in resonant frequency is 86.48 % compared to conventional patch antenna [8]. The electrical path length of meandered slot on patch geometry and meandered ground are increased surface current on patch antenna are responsible for higher degree of reduction in resonant frequency. The measured efficiency is 87 % whereas the simulated value is 89 %. It can be stated that the meandered patch antenna is highly efficient.

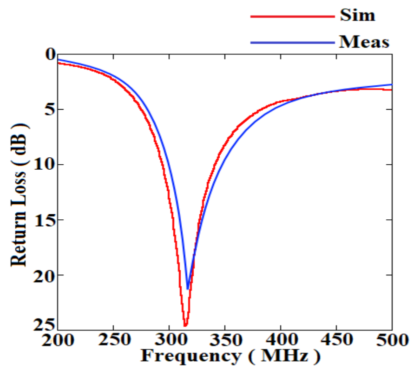
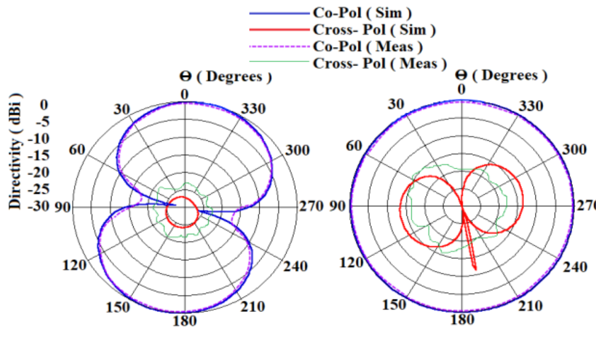


Fig. 2 – Measured and simulated return loss characteristics



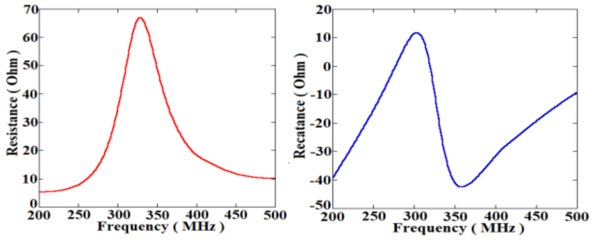
(a) (b)

Fig. 3 – Radiation characteristics (a) *E*- plane (b) *H*- plane

The radiation characteristics are depicted in Figure 3 (a, b). It is evident that its radiation pattern is an omnidirectional. The meandered section stimulates the patch in such a way that the patch permits high levels of back radiation, providing the antenna omnidirectional characteristics. It can be a good choice because of unique properties of this patch antenna.

Table 1 – Comparison of antennas with past works in respect to resonant frequency, efficiency, frequency reduction and design complexity

Ref.	Antenna Topology	Resonant Frequency (± 10)	Dimension (mm^3)	Effi-ciency (%)	Freque-ncy Reduc-tion	Design comple-xity
[1]	Printed Monopole antenna	315 MHz	161.90 × 16.19 × 1.99	Low	–	Complex
[2]	Sleeve Meander Monopole	434 MHz	165 × 42 × 1.60	–	78 %	Moderate
[3]	Loop antenna	315 MHz	20(*L*) × 10(*H*) × 1(*D*)	Low	–	Moderate
[3]	Whip antenna	315 MHz	20(*L*) × 10(*H*) × 1(*D*)	High	–	Moderate
[6]	Monopole antenna	868 MHz	400 × 400 × 78	–	–	Moderate
[6]	Low profile dual-band loop	868 MHz	400 × 400 × 1.5	–	–	Moderate
[4]	Inverted-F antenna (IFA)	433.92MHz	75.5 × 26.5 × 15	–	–	Moderate
[5]	Ultra small Helical with tap feed	315 MHz	12(*D*) × 9.5(*H*) × 10(*N*)	9.42	–	Complex
[5]	Ultra small helical with parasitic	315 MHz	12(*D*) × 11.6(*H*) × 13.5(*N*)	10.79	–	Complex
[7]	Meandered Slot Antenna	413 MHz	170 × 20 × 1.58	Low	–	Moderate
[18]	Compact Slot Antenna	434 MHz	170 × 20 × 1.58	78.56	–	Moderate
This work	**Patch Antenna**	**315 MHz**	**60 × 51 × 1.6**	**89**	**86.48 %**	**Simple**



(a) (b)

Fig. 4 – Input impedance characteristics (a) Resistance (b) Reactance

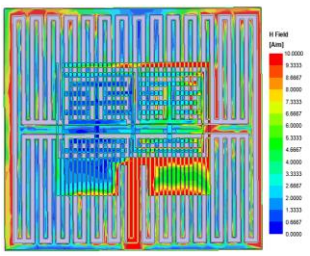
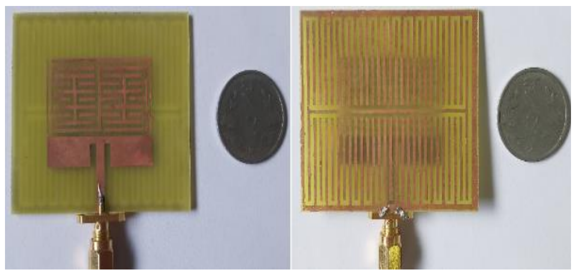


Fig. 5 – *H*-field plot

The *E*-plane characteristic has acceptable simulated and measured response. In *H*-plane, measured the cross-pol level are less than 15 dB compare with the co-pol. It has been indicated from Figure 4 (a, b) that resistance and reactance value are much closed to 50 Ω and 0 Ω respectively at 315 MHz resonant frequency. Figure 5 depicts the *H*-field plot for the patch antenna.

In the literature [1], printed meandered monopole antenna with shorting pin is used to obtain the ideal frequency. However in this work, we have avoided the usage of shorting pins and have employed a simple design, yielding the frequency required for short range wireless communication including vehicular application such as tire pressure monitoring system, remote keyless entry and etc. In comparison to the literature [1, 3, 5], it is clearly pointed that efficiency for the meandered patch antenna is high in compare to the existing work. The loop and whip antenna [3] is located above the printed circuit board (PCB). The antenna is 10 mm height above the PCB plane. The antenna is 20 mm long along the short edge of the PCB. Both antennas were developed close to the edge of the PCB to keep them separate from the than the actual antenna size, which is not men tioned in the literature. The length of tap feed (t) in an ultra-small helical antenna is 48.4 mm mentioned in [5]. Each helical antenna has a specific number of turns on copper wire, with 10 and 13.5 turns respectively, to achieve the desired results, paper has a drawback that is number of copper wire turns and it is expands the volume of this antenna. In contrast to available literature, it can be asserted that the proposed patch antenna is appropriate for short range wireless communications applications particularly in United States and Japan.



(a) (b)

Fig. 6 – Fabricated prototype of the patch antenna (a) Top view (b) Bottom view

Comparison of antennas with past works in respect to resonant frequency, efficiency and frequency reduction for short ranges wireless application tabulated in Table 1. It can be stated that the compact patch antenna is better comparison with existing research work. Comparison table with recent works in respect of reduced resonant frequency presented in Table 2.

Table 2 – Comparison table with recent works in respect to antenna size, resonant frequency, reduced resonant frequency.

Ref., Year	**Antenna Topology**	**Antenna Size (λ_0 = wave length)**	**Resonant Frequency**	**Band-width (– 10 dB)**	**Frequency Reduction**
[20], 2021	Metasurface Antenna	$0.48\lambda_0 \times 0.48\lambda_0 \times 0.06\lambda_0$	6.67 GHz	–	42 %
[14], 2013	Wire loading slot	$0.75\lambda_0 \times 0.75\lambda_0 \times 0.169\lambda_0$	2.32 GHz	–	45.52 %
[15], 2020	Slits and Strip loading slot	$0.212\lambda_0 \times 0.212\lambda_0 \times 0.010\lambda_0$	1.27 GHz	11.56 %	61.39 %
[19], 2020	Patch Antenna	$0.433\lambda_0 \times 0.433\lambda_0 \times 0.026\lambda_0$	2.6 GHz	–	63 %
[17], 2019	Slits and Strip loading slot	$0.21\lambda_0 \times 0.21\lambda_0 \times 0.010\lambda_0$	1.20 GHz	2.23 %	63.52 %
[16], 2022	Wheel loaded dipole	$0.108\lambda_0 \times 0.108\lambda_0 \times 0.162\lambda_0$	1.35 GHz	17.93 %	65.53 %
[13], 2022	Patch Antenna	$0.146\lambda_0 \times 0.124\lambda_0 \times 0.004\lambda_0$	0.729 GHz	–	68.44 %
This Work	**Patch Antenna**	$\mathbf{0.086\lambda_0 \times 0.073\lambda_0 \times 0.002\lambda_0}$	**315 MHz**	**14.46 %**	**86.48 %**

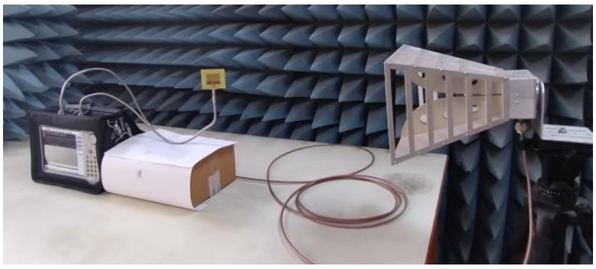


Fig. 7 – The measurement configuration for the patch antenna

4. CONCLUSION

In this communication, a compact low-profile, light weight antennas has been established, optimized, fabricated and measured for short range wireless communication application. This paper has evaluated the compact antenna implications by experimentally evaluating the printed proto-type. This antenna are optimized for reduced resonant frequency, making it suitable for short-range wireless communication at 315 MHz for United States and Japan. The antenna topology discussed in this communication a compact printed meandered patch ($0.086\lambda_0 \times 0.073\lambda_0 \times 0.002\lambda_0$) resonating at 315 MHz. This antenna exhibit corresponding band-width (10 dB) of 10.09 %. In simulation, the efficiency is measured at 89 %. Compared to a reference antenna, the design achieve significant reduction in resonant frequency is 86.48 %, providing valuable insights into the potential applications of such lower frequency resonance antenna in short-range wireless communication systems.

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Ефективна мініатюрна патч-антена для бездротового зв’язку малої дальності

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У статті досліджуються характеристики низькопрофільної, легкої патч-антени, виготовленої на епоксидній мікрохвильовій підкладці зі скла FR-4 з використанням мікросмужкового живлення 50 Ом. Антена розроблена для зниження резонансних частот, що робить її придатною для бездротового зв'язку на короткій відстані на частоті 315 МГц. У топології антени розглядається компактна меандрована патч-антена ($0.086\lambda_0 \times 0.073\lambda_0 \times 0.002\lambda_0$), що резонує на частоті 315 МГц. Ця антена демонструє відповідну смугу пропускання (10 дБ) 14,46 %. У моделюванні виміряна ефективність становить 89 %. Порівняно з еталонною антеною, конструкція досягла значного зниження частоти на 86,48 %, що вказує на потенціал для систем бездротового зв’язку на короткій відстані, що працюють на частоті 315 МГц. Проаналізовані втрати на відбиття, характеристики випромінювання та вхідний імпеданс, щоб забезпечити повне розуміння характеристик антени. Детально обговорюються деталі конструкції запропонованої топології антени, результати моделювання та експерименту.

Ключові слова: Компактна патч-антена, Ефективна антена, Мініатюризація, Бездротовий зв’язок.