Design and Analysis of a Penguin-Shaped Slot-Loaded Microstrip Patch Antenna for 5G Sub – 6GHz Applications

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***Abstract*—This paper presents the design and analysis of a compact microstrip patch antenna with a unique penguin-shaped slot-loaded structure for 5G Sub-6GHz applications. The antenna is developed using FR4 substrate material with dielectric constant 4.4 and thickness 1.6 mm. The proposed design uses circular and elliptical shapes to form the penguin structure. Slots are added to improve current flow and antenna performance. The antenna is simulated using CST Microwave Studio. The antenna resonates at 3.27 GHz with return loss of -18 dB and VSWR of 1.4. The directivity obtained is 6.85 dBi. The proposed antenna is compact, low cost, and suitable for wireless communication systems.**

***Index Terms*—Microstrip Patch Antenna, 5G, Sub-6GHz, Penguin Shape, Slot Antenna, CST**

I. INTRODUCTION

Wireless communication systems are rapidly developing with the growth of 5G technology. These systems require compact and efficient antennas capable of operating in the Sub-6GHz frequency range. This frequency band is widely preferred because it offers better coverage, low latency, and strong signal penetration compared to millimeter-wave frequencies. Therefore, antenna design plays an important role in achieving reliable communication performance.

Microstrip patch antennas are widely used because of their low cost, light weight, simple structure, and easy fabrication. They can also be easily integrated with printed circuit boards and portable electronic devices. Because of these advantages, microstrip antennas are commonly used in mobile phones, Wi-Fi routers, IoT devices, satellite systems, and modern wireless networks. However, conventional patch antennas suffer from narrow bandwidth, low gain, and reduced efficiency. These limitations affect their performance in advanced communication systems. To overcome these drawbacks, different techniques such as slot loading, shape modification, feed optimization, and substrate selection are commonly used.

In this work, a penguin-shaped microstrip patch antenna is proposed for Sub-6GHz 5G applications. The creative geometry improves current distribution and tuning characteristics while maintaining compact size. Slots are introduced in suitable regions to enhance impedance matching and radiation behavior. The antenna is designed using FR4 substrate and analysed using CST Microwave Studio. The obtained results show that the proposed antenna provides acceptable performance for modern wireless communication applications. The obtained results show that the proposed antenna provides acceptable performance for modern wireless communication applications.Thus, the proposed design offers a simple and effective solution for future compact wireless devices.

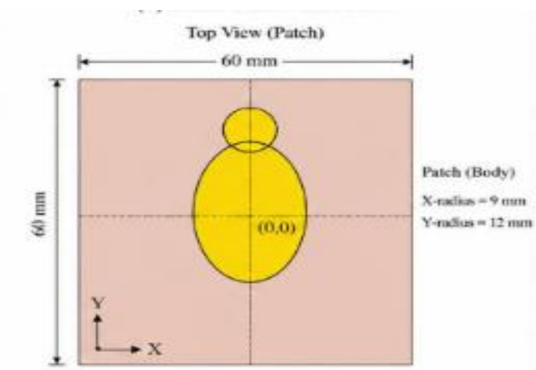
II. ANTENNA METHODOLOGY

The proposed antenna is developed as a compact penguin-shaped slot-loaded microstrip patch antenna for 5G Sub-6GHz applications. A conventional patch structure is modified using circular and elliptical geometries to create the penguin shape. This special geometry improves current distribution and enhances radiation characteristics.

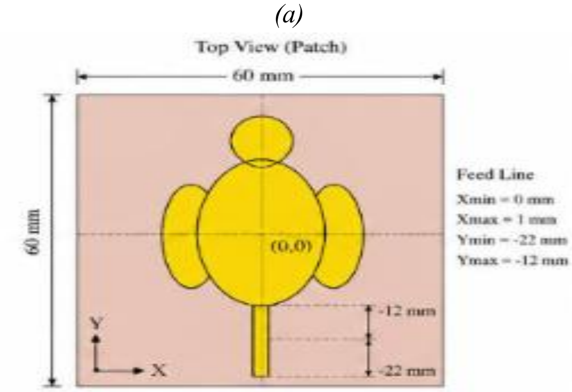
The antenna is fabricated on an FR4 substrate having a dielectric constant of 4.4 and thickness of 1.6 mm. Copper material is used for both the radiating patch and ground plane. A microstrip line feed is employed

to provide efficient power transfer to the antenna.

Slots are incorporated in suitable regions of the patch to achieve better impedance matching and resonant characteristics. The antenna is modeled and analyzed using CST Microwave Studio. The final optimized design resonates at 3.27 GHz with good return loss, acceptable VSWR, and a stable radiation pattern.



(a)



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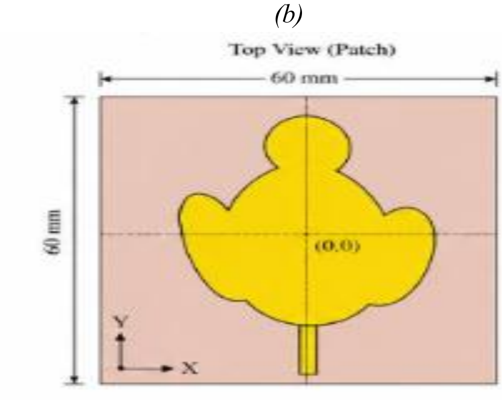

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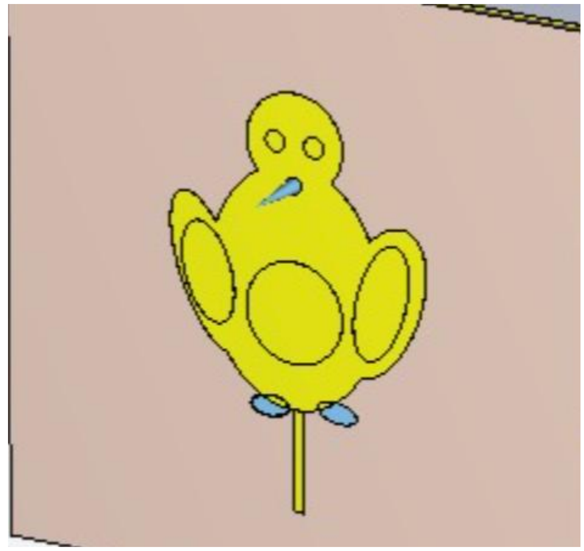


(d)

Fig 1. (a), (b), (c), (d): Penguin Shaped slot loaded microstrip patch antenna and its evolution

A. Penguin-Shaped Antenna Geometry

The radiating patch is designed in a unique penguin shape using elliptical and circular sections for the body, head, and wings. This creative geometry helps in controlling the surface current path and improving radiation characteristics. The compact structure also reduces the overall antenna size while maintaining desired operating frequency. The symmetrical arrangement of different sections provides balanced current flow. It also gives an attractive and innovative appearance without affecting antenna performance

B. FR4 Substrate Selection

FR4 substrate with dielectric constant 4.4 and thickness 1.6 mm is used in the proposed design. It is selected because of its low cost, easy fabrication, light weight, and suitable dielectric properties for microwave applications. The substrate also provides good mechanical support to the antenna structure.

C. Microstrip Feed Line Design

A microstrip line feed is used for antenna excitation. It provides a simple structure and efficient power transfer from the source to the radiating patch. The feed dimensions are carefully chosen to achieve proper impedance matching and reduce reflection losses at the operating frequency. This feeding technique is easy to integrate with the patch structure. It also supports convenient fabrication and stable antenna operation.

D. Slot Loading Structure

Slots are added in the penguin-shaped patch to improve antenna performance. These slots help in modifying the surface current distribution and tuning the resonant frequency. They also improve return loss and impedance matching. The slot arrangement increases the effective current path on the patch surface. This technique is useful for achieving compact size with better performance.

E. Ground Plane Structure

A copper ground plane is placed below the substrate. It acts as a reference plane for the antenna and supports proper radiation. It also helps in reducing unwanted back radiation and improves stability. The ground plane enhances impedance characteristics of the antenna. Proper ground dimensions are important for achieving better overall performance.

F.CST Simulation and Optimization

The complete antenna is designed and analyzed using CST Microwave Studio. Different parameters such as patch size, feed dimensions, and slot positions are optimized through simulation. This process helps in obtaining better gain and return loss. The software provides accurate electromagnetic analysis of the antenna model. Repeated optimization improves resonance and radiation characteristics.

G. Design Objective for 5G Applications

The main objective is to develop a compact and efficient penguin-shaped antenna for 5G wireless applications. The antenna should provide stable radiation, proper resonance, and low fabrication cost. It must also support modern communication needs. Another aim is to achieve good impedance matching at the desired frequency. The design should be suitable for portable and compact devices.

H.Antenna Performance Evaluation

The antenna performance is evaluated using parameters such as return loss, VSWR, gain, and radiation pattern. These values indicate the efficiency and suitability of the antenna. Good results confirm effective operation. Lower return loss ensures better power transfer. Stable radiation pattern indicates reliable communication performance.

I. Wireless Communication Applications

The proposed antenna is suitable for 5G Sub-6GHz systems, IoT devices, WLAN, and other compact wireless applications. Its small size makes it useful for portable devices. It can also be used in modern communication equipment.

J. Easy Fabrication Method

The antenna uses simple geometrical shapes and FR4 substrate, making fabrication easy and economical. Standard PCB manufacturing methods can be used for practical implementation. This reduces overall production cost.

Table 1: Antenna parameters

PARAMETER	VALUE
Substrate Size	60 × 60
Substrate Thickness	1.6 mm
Ground Size	60 × 60
Ground Thickness	0.035 mm
Feed Length	10 mm
Feed Width	0.95 mm
Body Size	18 × 24 mm
Head Radius	5 mm
Left Wing Size	6 × 16 mm
Right Wing Size	8 × 16 mm

III. RESULT AND DISCUSSION

The proposed penguin-shaped slot-loaded microstrip patch antenna is designed and simulated using CST Microwave Studio to evaluate its performance for 5G Sub-6GHz wireless communication applications. The antenna performance is analyzed using important parameters such as return loss (S11), VSWR, gain, directivity, surface current distribution, and radiation pattern. The obtained results indicate that the proposed antenna provides good resonance characteristics, efficient radiation performance, and stable operation with compact size. The creative patch geometry and slot-loading structure play an important role in enhancing the overall antenna characteristics.

The simulation results also confirm that the antenna can meet the requirements of modern compact wireless devices. The proposed design offers a balance between size reduction and improved electrical performance.

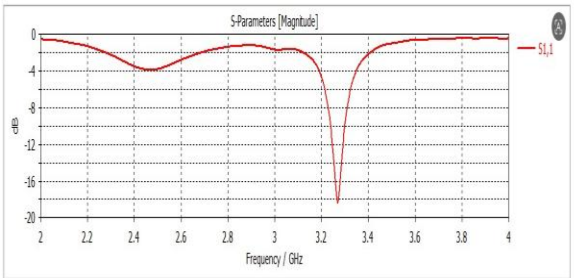


Fig 2: Simulated return loss (S11) of the Penguin shaped antenna

The proposed antenna shows a return loss of −18 dB at 3.27 GHz, which indicates good impedance matching and strong resonance. Since the value is below −10 dB, most of the input power is radiated with minimum reflection loss. This confirms efficient antenna performance at the operating frequency. The obtained result shows that the antenna is properly tuned for the desired band. It also improves communication quality by reducing signal loss. The lower reflection enhances overall transmission efficiency. This makes the antenna suitable for practical wireless applications.

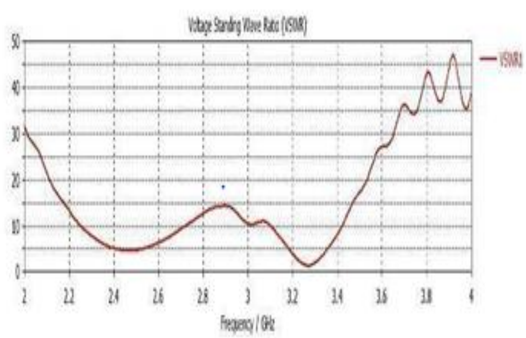


Fig 3: VSWR of the penguin shaped antenna

The proposed antenna shows a VSWR value of 1.4 at the resonant frequency, which indicates good impedance matching and efficient power transfer. Since the VSWR value is less than 2, the antenna has minimum mismatch losses. This confirms stable antenna performance at the operating frequency. It also ensures reliable signal transmission for wireless applications. The obtained value shows that the antenna is properly tuned to the desired frequency. It also helps in reducing reflected power during operation.

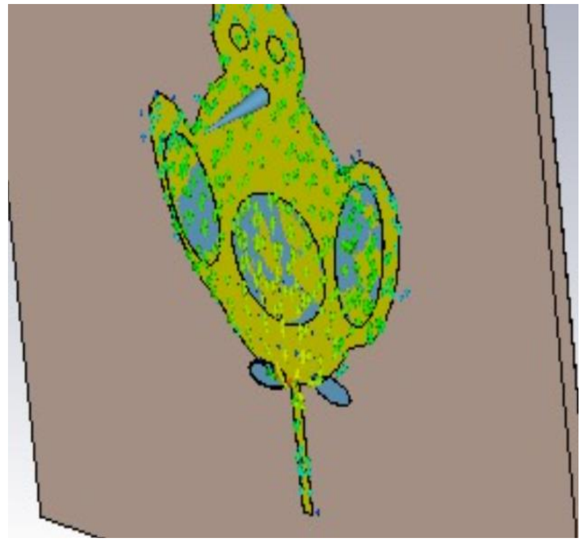
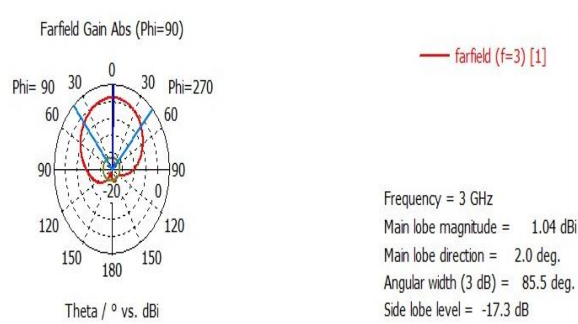
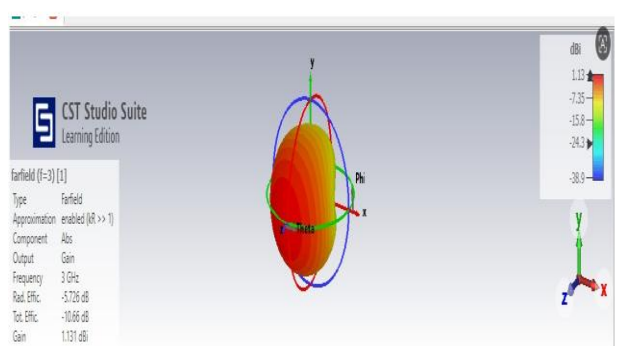


Fig 4: Surface Current Distribution of the Penguin shaped antenna

The surface current distribution shows that the current is mainly concentrated near the feed region and lower patch area. Proper current flow is also observed on the body and wing sections of the penguin shape. This confirms that the proposed geometry supports effective radiation and resonance.



(a)



(b)

Fig 5: (a) 1D plot (b) 3D plot

Radiation patterns in one-dimensional (1D), and three-dimensional (3D) planes

The proposed antenna shows a stable far-field radiation pattern in 1D and 3D views.

In the 1D radiation plot, the antenna exhibits a clear main lobe with proper directional characteristics. The radiation pattern shows symmetrical broadside radiation with balanced energy distribution in the desired direction. The 3D far-field pattern confirms effective overall radiation coverage and stable antenna performance. These results indicate that the antenna is suitable for reliable wireless communication applications.

Table 2: Comparison of the Penguin Shaped Antenna with Reference Designs

Reference	Frequency (GHz)	Return loss(dB)	VSWR	Antenna Type
[2]	2 - 3	-10 to -15	1.5 - 2	Rectangular Patch
[8]	2 - 5	-10 to -15	1.5 - 2	Wideband Patch
[10]	3 - 5	-15	~ 1.5	Compact Patch
[16]	2 - 4	-15	~1.5	Wide-slot Patch
Proposedwork	3.27	-18	1.4	Penguin Slot Antenna

The comparison table clearly shows that the proposed penguin-shaped antenna provides better performance when compared with existing reference antennas. It achieves a return loss of −18 dB and a VSWR of 1.4, indicating good impedance matching and efficient power transfer. The compact structure also maintains acceptable radiation characteristics. From the tabulated results, the proposed design is suitable for 5G Sub-6GHz and modern wireless communication applicationsThe table also indicates that the proposed antenna resonates at the desired frequency of 3.27 GHz with stable performance. Compared to conventional rectangular and wide-slot antennas, the proposed design offers improved electrical characteristics with reduced size. The results confirm that the penguin-shaped geometry does not affect antenna efficiency. Instead, it helps in achieving better tuning and resonance behavior. Therefore, the proposed antenna can be considered as an effective and innovative design for practical wireless systems.The obtained results also optimal compromise among compactness, simplicity, and electromagnetic functionality. Therefore, this antenna can be used in real wireless communication systems like WLAN, Bluetooth, and IoT at the 2.4 GHz frequency band.

IV. CONCLUSION

The proposed penguin-shaped slot-loaded microstrip patch antenna has been successfully designed and analyzed for 5G Sub-6GHz applications using CST Microwave Studio. The antenna resonates at 3.27 GHz with a return loss of −18 dB and a VSWR of 1.4, which confirms good impedance matching and efficient power transfer.

The unique penguin-shaped geometry and slot-loading technique help in improving current distribution, resonance characteristics, and radiation performance. The antenna also provides stable far-field radiation pattern with acceptable directivity for wireless communication systems.

The compact size, simple structure, and low-cost FR4 substrate make the antenna suitable for practical implementation. Therefore, the proposed design can be effectively used in 5G systems, WLAN, IoT devices, and other modern wireless communication applications. Future work can focus on fabrication and further performance enhancement.

REFERENCE

[1] C. A. Balanis, Antenna Theory: Analysis and Design, 3rd ed., Wiley, 2005.

[2] D. M. Pozar, “Microstrip antennas,” Proceedings of the IEEE, vol. 80, no. 1, pp. 79–91, Jan. 1992.

[3] K. L. Wong, Compact and Broadband Microstrip Antennas, Wiley, 2002.

[4] J. R. James and P. S. Hall, Handbook of Microstrip Antennas, IET, 1989.

[5] R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, Microstrip Antenna Design Handbook, Artech House, 2001.

[6] H. Wong and K. M. Luk, Recent Advances in Microstrip Antennas, Wiley, 2015.

[7] S. Maci and G. B. Gentili, “Dual-frequency

patch antenna designs," IEEE Antennas and Propagation Magazine, vol. 39, no. 6, pp. 13–20,
Dec. 1997.

[8] M. A. Matin, "A review on wideband microstrip patch antennas," International Journal of Engineering and Technology, 2010.

[9] A. K. Arya and M. V. Kartikeyan, "Design considerations of microstrip patch antennas for wireless systems," International Journal of Electronics, 2013.

[10] S. A. Kumar and T. Shanmuganantham, "Compact microstrip antenna design for 5G applications," International Journal of Communication Systems, 2018.

[11] P. K. Singhal and A. K. Singh, "Analysis and design of microstrip patch antennas for 5G communication," International Journal of Microwave Engineering, 2019.

[12] N. Ojaroudi et al., "Design of compact microstrip slot antennas for wireless applications," IEEE Antennas and Wireless Propagation Letters, 2014.

[13] J. S. Hong and M. J. Lancaster, Microstrip Filters for RF/Microwave Applications, Wiley, 2001.

[14] "Recent advancements in microstrip antennas for 5G systems," IEEE Xplore Digital Library, 2023.

[15] A. B. Smolders et al., "Compact antenna systems designed for 5G communication," IEEE Communications Magazine, 2017.

[16] J. Y. Sze and K. L. Wong, "Enhancing bandwidth of microstrip-line-fed wide-slot antennas," IEEE Transactions on Antennas and Propagation, vol. 49, no. 7, pp. 1020–1024, Jul. 2001.

[17] Y. F. Liu, P. Wang, and H. J. Li, "Compact slot-loaded microstrip patch antenna for wireless applications," IEEE Antennas and Wireless Propagation Letters, vol. 12, pp. 123–126, 2013.

[18] M. Samsuzzaman, M. T. Islam, and N. Misran, "Compact microstrip patch antenna design for 5G communication systems," International Journal of Antennas and Propagation, 2016.

[19] A. A. Deshmukh and K. P. Ray, "Broadband and compact microstrip antenna designs," IEEE Antennas and Propagation Magazine, vol. 51, no. 6, pp. 41–56, Dec. 2009.