1. Jeevitha J, 2. Shine Let G, 3. H Victor Du John, 4. Benin Pratap C

Karunya Institute of Technology & Sciences

ORCID: 1. 0000-0002-4180-7025; 2. 0000-0002-8800-3446; 3. 0000-0002-9889-2566; 4. 0000-0002-4717-9015

doi:10.15199/48.2023.05.16

A Compact Hook-Shaped 3.5 GHz Microstrip Antenna for 5G Applications

***Abstract**. The 5G N77 band resonating at 3.5 GHz is addressed by a compact (20 mm x 12 mm x 0.8 mm) hook-shaped microstrip antenna which is presented in this paper. The suggested planar patch is printed on the inexpensive FR-4 substrate of 0.8 mm thickness. The proposed hook-shaped antenna is fabricated and its network parameters are measured using a Network analyzer. The fabricated antenna results closely match the simulated network parameter results. In E-plane and H-plane analyses of the radiation characteristics of the hook-shaped antenna, favorable outcomes are obtained. The suggested antenna had a 1.9 dB gain and 93% radiation efficiency, making it an appropriate option for 5G wireless applications.*

Streszczenie**. Pasmo 5G N77 rezonujące na częstotliwości 3,5 GHz jest adresowane przez kompaktową (20 mm x 12 mm x 0,8 mm) haczykową antenę mikropaskową, która jest prezentowana w tym artykule. Proponowana łata płaska drukowana jest na niedrogim podłożu FR-4 o grubości 0,8 mm. Proponowana antena w kształcie haka jest wytwarzana, a jej parametry sieciowe są mierzone za pomocą analizatora sieci. Wyniki wytworzonej anteny są ściśle zgodne z wynikami symulowanych parametrów sieci. W analizach E-płaszczyznowych i H-płaszczyznowych charakterystyk promieniowania anteny hakowej uzyskuje się korzystne wyniki. Sugerowana antena miała zysk 1,9 dB i wydajność promieniowania 93%, co czyni ją odpowiednią opcją dla aplikacji bezprzewodowych 5G.* (Kompaktowa antena mikropaskowa 3,5 GHz w kształcie haczyka do zastosowań 5G***
)

Keywords: Hook-shaped, 5G Applications, Microstrip Antenna, Compact design.
Słowa kluczowqe: antena mikropaskowa, 5G

Introduction

In the modern world, wireless communication offers affordable, fast, and flexible communication and the fifth generation (5G) is the latest generation of cellular mobile communications. The frequency bands used in 5G fall into two categories: (i) those under 6 GHz and (ii) those over 20 GHz and up to 80 GHz. The sub-6 GHz frequency spectrum for 5G connectivity lies between 3.4 and 3.6 GHz. Most countries have allowed the use of the 3.5 GHz frequency range, which is universally acknowledged [1]. A microstrip patch antenna is a successful implementation method for the most recent 5G technology antenna design. The primary goal of this paper is to propose a simplistic, compact rectangular Microstrip antenna operating at 3.5 GHz.

Wireless communication systems have used microstrip patch antennas, but due to the huge radiating surface area, these antennas have limited gain and power handling capacity. It is challenging to develop compact wideband and ultra-wideband antennas that meet requirements like greater impedance bandwidth, appropriate gain, and simplicity of fabrication. The bandwidth restriction is typically addressed using a variety of methods, such as changing substrates, cutting slots in the patch, using a layered patch antenna, increasing the substrate's thickness, etc. An elliptical Microstrip patch antenna (25.2 × 48 x 1.6) mm^3 that operates at a 3.5 GHz band with an FR4 substrate by the authors in [1]. The antenna's efficiency was 96.67%, and its gain was 5.01 dB. A microstrip patch antenna with high gain and directivity at 3.5 GHz was constructed by the authors in [2]. An S_{11} value of -19 dB and a bandwidth of around 20 MHz are the outcomes. A hook-shaped antenna with dimensions (33 × 18 x 1.6) mm^3 with FR4 substrate achieved a return loss of -21dB [4]. The work portrayed in [5] is a rectangular slot antenna (32.4×27.9×1.6) mm^3 using FR4 substrate, attaining a return loss of -26.5 dB and an efficiency of 82%. A rectangular multistrip patch antenna (33 x 28.8 x 1) mm^3 with RT duroid substrate, achieved attained return loss of -19.33 dB and efficiency of 98.21% [6].

In this work, a simple miniaturized (20 mm × 12 mm) microstrip antenna is designed, simulated, manufactured, and verified experimentally. The branches of the proposed antenna must be compact in order to attain a compact design. The performance of a miniaturized antenna operating in the 3.5 GHz (3.4-3.6 GHz) band has been improved using straightforward rectangular radiating stripes. In the sections that follow, the specifics of the antenna design and the results are covered.

Antenna Configuration

The proposed hook-shaped microstrip antenna structure's geometry is shown in Fig. 1. The hook-shaped antenna consists of three layers and has a substrate with a total size of 20 mm x 12 mm. The middle layer is of an FR4 substrate that is 0.8 mm thick and is shown in Fig. 1 by the yellow color (ε_r = 4.4, dielectric loss tangent = 0.02). On the top side of the substrate, a hook-like radiating structure is proposed and is depicted in green color in Fig. 1. A partial rectangular ground plane is incorporated in the design. Ground plane dimensions are reported as $L_g \times W_g$ = 2 mm × 11.5 mm.

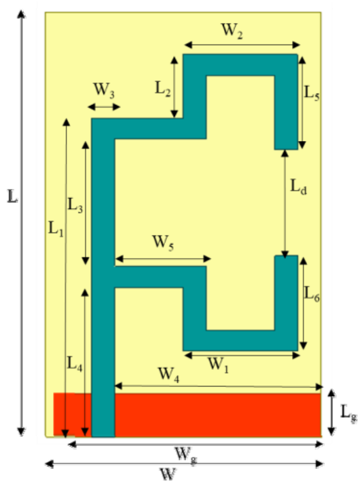

Fig.1. Hook-shaped microstrip antenna's geometry

The proposed design structure is compact and straightforward. Hence, it can be easily integrated with other communication system blocks. The construction is optimized and simulated using the 3D electromagnetic modeling software HFSS. The antenna dimensions are enhanced using parametric analysis, and the significant values are presented in Table 1.

Table 1. Hook-shaped microstrip antenna's dimensions

Parameter	Dimensions [mm]	Parameter	Dimensions [mm]
L	20	L_5	4.5
W	12	L_6	4.5
L_g	2	W_1	5
W_g	11.5	W_2	5
L_1	15	W_3	1
L_2	3	W_4	8
L_3	6	W_5	4
L_4	7	L_d	5

Parametric study

To identify the optimal dimensions for an improved antenna network and radiation characteristics, a thorough parametric investigation is carried out. In this part, the impact of varying the length (Lg) and width (Wg) of a rectangle-shaped ground and the length (L5 and L6) of a hook-shaped radiating structure is carefully investigated. In Fig. 3 the variation of ground plane size in the x-direction (L_g) is plotted. As the size increases, the antenna radiation at 3.5 GHz is reduced and is closer to -10 dB. The decrease in ground length has an effect on the operating frequency range. The antenna operating frequency is shifted to less than 3.5 GHz for the ground size of 1 mm. The optimum value of 2 mm ground size provides the defined operating frequency. Similarly, the size of the ground is altered in the y-direction (W_g) to tune the antenna for the 5G application N77 band, as is shown in Fig. 4. The change in W_g has very less significance in the reflection coefficient. To select the exact operating frequency range in the N77 band W_g = 11.5 mm is considered as the nominal value to have better performance.

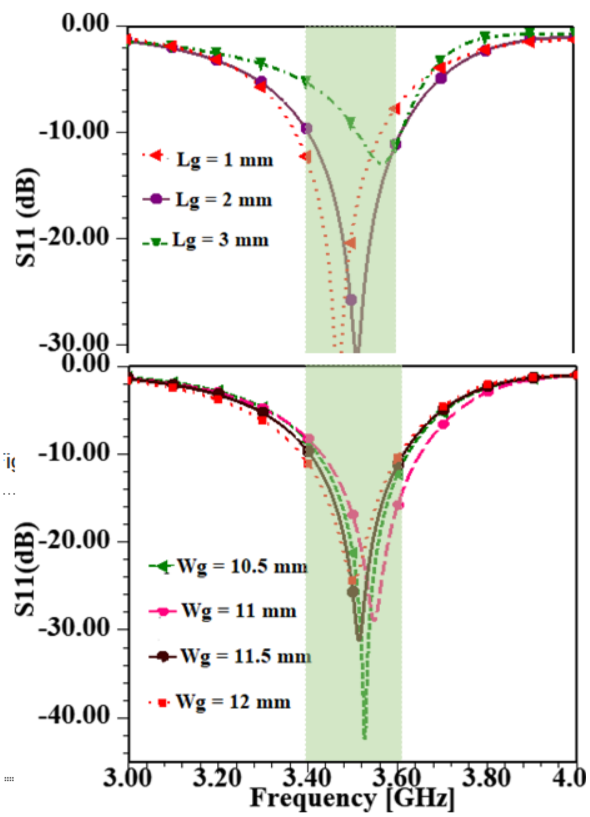

Fig. 4. Variation of S_{11} based on W_g parameter

In the hook-shaped radiating structure, the length of the hook is finalized by the parametric study. As the size of the hook (L_5 and L_6) alters, this alters the gap 'L_d'. Fig. 5 illustrates the L_5/L_6 variation. As the length of the radiating strips (L_5 and L_6) increases, the antenna operating frequency shifts to the lower frequency band from the desired band 3.4 GHz to 3.6 GHz. When the radiating length decreases, the resonant frequency shifts to the higher frequency band from 3.5 GHz. By using a parametric study, the optimum value fixed for the lengths L_5 and L_6 is 4.5 mm.

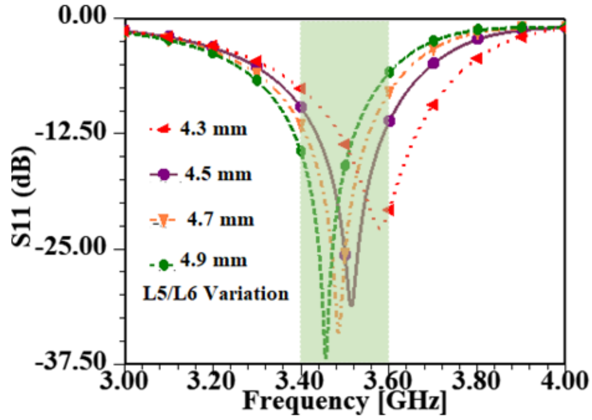

Fig. 5. Variation of S_{11} based on L_5/L_6 parameter

Radiation Characteristics

The distribution of the antenna's radiating energy in the far-field region is demonstrated by the radiation pattern. Fig. 6 shows the three-dimensional radiation pattern of the proposed antenna, which demonstrates omnidirectional radiation with a gain of 1.9 dBi at 3.5 GHz. The two-dimensional radiation pattern for desired frequency is plotted in the H-plane and E-plane as shown in Fig. 7. The blue solid line in Fig. 7 depicts the co-polarization radiation characteristics and the red dotted line points out the cross-polarization characteristics.

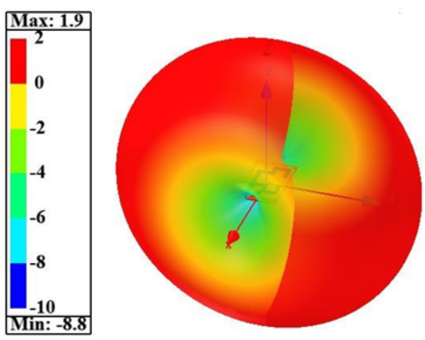

Fig. 6. The 3D view of the radiation pattern for the proposed antenna model at 3.5 GHz frequency.

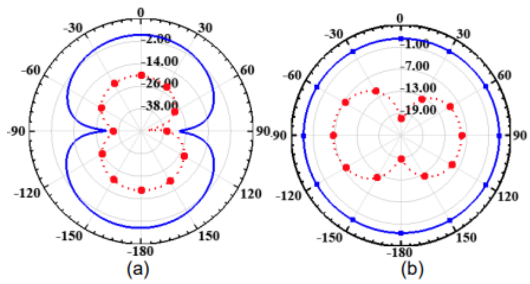

Fig.7. Simulated hook-shaped microstrip antenna radiation pattern (a) H-plane (b) E-plane

Fabricated hook-shaped microstrip antenna

The simulated hook-shaped microstrip antenna is fabricated in an FR4 substrate of 0.8 mm thickness for the substrate dimensions of 20 mm x 12 mm and is shown in Fig. 8. The network characteristics of the antenna are measured using a network analyzer. The measurement setup is shown in Fig. 9. The reflection coefficient characteristics of the fabricated and simulated antenna match well. The operating frequency range of fabricated hook-shaped is from 3.36 GHz to 3.6 GHz with comes within the N77 band used for 5G mobile applications.

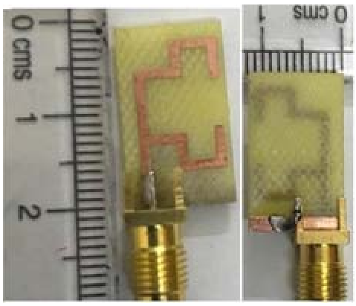
Fig.8. Fabricated hook-shaped microstrip antenna

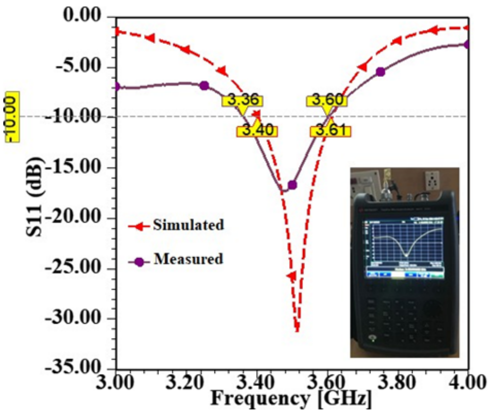

Fig.9. Hook-shaped microstrip antenna simulated and measured S_{11} characteristics

Table.2 provides various comparisons of the proposed hook-shaped antenna with other literary works carried out at the resonant frequency of 3.5 GHz. Most of the antenna design is carried out in the FR4 substrate of 1.6 mm thickness. Currently, all the electronics equipment designed takes enough consideration about space occupancy and miniaturization. This work is designed in an easily available 0.8 mm thickness substrate with less occupancy of space in the electronic board.

Table. 2 Performance comparison among microstrip antenna at 3.5GHz

Ref	Dimensions [mm]	Substrate	Thickness	S_{11}(dB)	Efficiency
[3]	32 × 18	FR4	1.6	-21	-
[4]	30 x 30	FR4	1.6	-12	-
[5]	32.4x27.9	FR4	1.6	-26.5	82%
[6]	33 x 28.8	RT duroid	1	-19.33	98.21%
[7]	35 x 40	FR4	1.6	-23.5	-
Proposed	20 x 12	FR4	0.8	-32	93.8

Conclusion

In this paper, a compact hook-shaped microstrip antenna is proposed for a 5G wireless communication system. The proposed microstrip patch antenna was simulated and printed by HFSS, with an overall size of 20 × 12 × 0.8 mm^3. The hook-shaped antenna operating frequency is from 3.4 GHz to 3.6 GHz with a resonant frequency at 3.5 GHz and a return loss of -32 dB. The proposed antenna gain is 1.9 dB and the antenna efficiency is 93.8% at a 3.5 GHz resonant frequency. The characteristics of the measured and simulated results' reflection coefficients taken into account for the operating frequency range are very similar. The suggested design gain, radiation characteristics, and reflection characteristics make the hook-shaped antenna appropriate for diverse wireless communications, including 5G mobile applications.

Acknowledgments: *The authors would like to acknowledge the assistance provided by the Microwave laboratory and RF laboratory, Karunya Institute of Technology and Sciences, Tamil Nadu, for providing an antenna simulation, fabrication, and testing facility.*

Authors. *Jeevitha J, Shine Let G, H Victor Du John, Benin Pratap C, Karunya Institute of Technology and Sciences.*
E-mail: jeevithajoseph@gmail.com, shinelet@gmail.com, victorjohn@karunya.edu, pratapbenin@gmail.com

REFERENCES

[1] Ferdous, N., Hock, G. C., Hamid, S. H. A., Raman, M. N. A., Kiong, T. S., & Ismail, M. (2019, June). Design of a small patch antenna at 3.5 GHz for 5G application. In *IOP Conference Series: Earth and Environmental Science* (Vol. 268, No. 1, p. 012152

[2] A. Kumar, N. Kumar, N. Nitesh "Design of Microstrip Patch Antenna for High Gain & Directivity at 3.5 GHz by Simulation studies using ADS." *International Journal of Engineering Trends and Technology (IJETT)* – Volume 55 Number 1, 2018, pp. 26-33

[3] Zehforoosh, A., & Zehforoosh, Y. (2022). Evaluation of a novel hook-shaped multiband monopole antenna based on the AHP method. *IET Communications*, *16*(3), 266-273.

[4] Tu, D. T. T., Cao, S., & Duong, H. (2022). An open double ring antenna with multiple reconfigurable feature for 5G/IoT below 6GHz applications. *Bulletin of Electrical Engineering and Informatics*, *11*(1), 310-318

[5] Chowdhury, M. Z. B., Islam, M. T., Rmili, H., Hossain, I., Mahmud, M. Z., & Samsuzzaman, M. (2022). A low-profile rectangular slot antenna for sub-6 GHz 5G wireless applications. *International Journal of Communication Systems*, e5321.

[6] Elechi, P., & John, P. R. (2022). Improved Multiband Rectangular Microstrip Patch Antenna for 5G Application. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, *14*(2), 7-14.

[7] Geetharamani, G., & Aathmanesan, T. (2020). A metamaterial inspired tapered patch antenna for WLAN/WiMAX applications. *Wireless Personal Communications*, *113*(2), 1331-1343.