International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-13 Issue-8, July 2024

Improvements of the Bandwidth and Radiation Characteristics of a 5G Mobile Communications Microstrip Antenna with a Novel Wedge Shaped Substrate Design

Mouhamad S Abou Chahine, Mohamad Arnaout, Fatma Tangour, Mohamad-Youssef Abu Shahine

***Abstract**: In this study, a new approach for the design of microstrip antenna is proposed. The resonant frequency of the proposed antenna is 3.55 GHz allowing it to operate in the mobile network current 5G band (the mid band). The design approach is based on a wedge shaped substrate having relative low thickness at the level of the feed line and a higher thickness at the level of the radiating patch. The FR4 wedge substrate based design of 6 mm linear slope enhance the radiation by 9% and the bandwidth by 10.3 % while degrading the return loss by 2.3 dB with respect to a standard box substrate based antenna design of the same dimensions. To remedy the degradation in terms of S11, the rectangular inset feed line is replaced by a trapezium one which re-enhance the return loss by 3.4 dB and then making it better than the original one.*

***Keywords**: Bandwidth, Directivity, Inset Fed, Microstrip Antenna, Wedge Substrate, 5G Mobile Communication.*

I. INTRODUCTION

With the arrival of smartphones on the market sixteen years ago, the demand for large and high rate data traffic has continued to increase year after year. Before the era of smartphones, users only had the possibility of exchanging short message in addition to audio calls. Internet access via smartphones triggered the data intensive content user demand starting by video streaming and not ending by IoT applications. The infinit appetite for data intensive content associated with the explosion in the number of users push mobile network operators each time to ask network developers to improve the performance of the deployed networks. This is how the mobile network has undergone 5 major upgrades since its inception to reach the 5G. The key element that allow increasing the number of users while giving each of them more data traffic with more throughput is to increase the number of frequency channels by spacing them out as much as possible. This leads the developers each time to change the band of use in the frequency spectrum by going towards higher and higher frequencies.

Three frequency bands are to be used in a 5G system. The first one is the 700 MHz band (694 MHz-790 MHz). The second one is the 3.6 GHz band (3400 MHz-3800 MHz). The third one is the 28 GHz band (27.5 GHz – 28.35 GHz) [1], [2]. The second band constitute the corner stone of 5G system because it provides a good compromise between relatively low attenuation signal propagation and high spectral resources capacity [3].

Following the choice of this spectrum, it becomes necessary to adapt the elements of the communications network infrastructure to operate in this new band while keeping the performance criteria at a certain minimum acceptable level or even improving them, especially in terms of bandwidth and directivity. The most important network key element which needs to be rethought is the antenna.

In general, PCB antennas have the advantage of being accommodated easily in the device package. In addition, they are very economical and easy to produce. Microstrip antennas are the most popular form of PCB antennas because they are light in weight, smaller in size, low in cost and integrable with integrated circuits. At the same time, they have some drawbacks like the low gain and the narrow bandwidth [4], [5][31][32][33].

Having coplanar radiation elements and power supply, the microstrip patch antennas (MPAs) make it possible to establish a balance between manufacturing complexity on the one hand and good performance on the other hand [6]. However, MPA antennas pose a serious and critical problem because they have a high antenna quality factor (Q). Unfortunately, high Q leads to a narrow bandwidth and low efficiency which make their use in a broadband system such as the 5G systems inappropriate [7]. The main objective behind the work in this paper is to overcome the problem of narrow bandwidth of MPA by adding a new element to the design of the antenna while keeping the other design elements operational. In such a way, this will allow a net improvement of the bandwidth and the antenna gain regardless all the other design elements.

Manuscript received on 06 June 2024 | Revised Manuscript received on 17 June 2024 | Manuscript Accepted on 15 July 2024 | Manuscript published on 30 July 2024.
Correspondence Author(s)

Mouhamad S Abou Chahine*, LR2E Laboratory, ECAM-EPMI school of engineering, Cergy, France. E-mail: m.abou-chahine@ecam-epmi.com, ORCID ID: 0000-0002-8141-4613
Mohamad Arnaout, Department of Electrical and Electronics Engineering, International University of Beirut, Beirut, Lebanon. E-mail: mohamad.arnaout@liu.edu.lb.
Fatma Tangour, LR2E Laboratory, ECAM-EPMI school of engineering, Cergy, France. E-mail: f.tangour@ecam-epmi.com
Mohamad-Youssef Abu Shahine, Department of Electrical and Electronics Engineering, International University of Beirut, Beirut, Lebanon. E-mail: mohamad.aboushahine@liu.edu.lb.

Thus, combination of the proposed technique with other techniques becomes possible to obtain characteristics that are even better.

In high frequency, the dependence of the antenna performance criteria, such as directivity and bandwidth, on the dielectric substrate's and other electrical parameters becomes much more sensitive than in low frequency [8].

All the academic and industrial studies conducted until today on the design of microstrip patch antennas have proposed designs based on the exploration of all possible geometric shapes of the emanating part of the antenna. These shapes vary from rectangular to circular through Cross, Z, U, V and even Seljuk star shapes [9]-[14]. Several other studies have explored the effects of varying the antenna dimension elements on performance criteria. For example, [6],[15],[16] explored the effect of varying substrate thickness and patch width on the antenna bandwidth and gain.

This study presents a new approach for the design of MPA. The key element of this approach is the use of a wedge-shaped substrate instead of a box-shaped one. While [17] proposed only a theoretical calculation of the resonant frequency of a rectangular patch antenna mounted on a wedge-substrate without a feed line, this study presents a practical wedge-substrate antenna equipped with a feed line and demonstrates the enhancement of all the antenna performance criteria especially in terms of bandwidth except the return loss with respects to the same patch antenna when it is constructed on a conventional box-substrate. The study concludes by proposing a new design for the feed line of the wedge-substrate antenna that correct the degradation of the return loss and even produces a result much better than the wedge-substrate design and the standard prevalent box-substrate design.

Wedge shaped microstrip antenna

A practical microstrip antenna is composed mainly of 2 parts: the radiating patch and the microstrip feed line relating the input connector to the radiation element. Of course, these two parts are etched on a dielectric substrate separating them from the ground plane of the antenna.

Because the feed line is a straight line, it will not radiate. The reason radiation is prevented in this type of line is its symmetry allowing the fringing fields along the line to be balanced and then obtaining the cancellation of any radiated energy. This is not the case of the patch due to its discontinuity at the ends. Microstrip antenna are characterized by an electric field equal to zero at the center of the patch. On the other hand, at the edges of the patch, an electric field is radiated. This radiation is due to the exceeding fringing field between the edge of the patch and the ground plane. The magnitude of the fringing field is a function of the dimensions of the patch and is at the same time proportional to the thickness of the substrate [18].

Accordingly, the radiation is directly proportional to the thickness of the substrate. Thus, a high thickness at the level of the patch is preferred in order to improve the radiation and then enhance the gain of the antenna. However, a lower thickness at the level of the feed line is appreciated in order to limit the radiation losses. While standard box substrate antenna does not offer this combination because the thickness is the same everywhere on the device, it becomes possible to combine low thickness transmission line with high thickness patch antenna if a wedge shaped substrate is used. The radiation is not the only characteristic that depend on the thickness. Another important antenna characteristic is directly related to the thickness. It is the bandwidth of the antenna as it will be demonstrated in the next section. Figure 1 presents a conceptual geometry of a wedge shaped patch antenna. This study will demonstrate the enhancement mainly of the bandwidth and the radiation in addition to other performance parameters with the use of this concept approach by comparing the performance criteria of two antennas. The two antenna will have the same upper layer geometry while the first will be mounted on a rectangular box substrate and the second will be mounted on a wedge substrate.

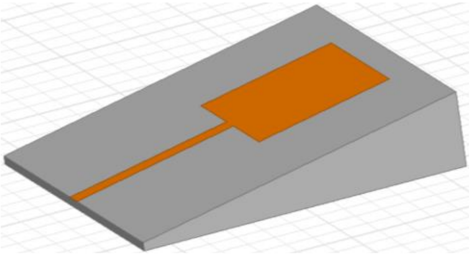

Fig.1. Geometry of a Wedge-Shaped Patch Antenna

II. CIRCUIT DESIGN

The dimensions of MPA depend on many variables but mainly on the resonance frequency on one hand and on the thickness and the permittivity of the dielectric layer on the other hand. As said before, the antenna in this study is designed to operate at a center frequency of 3.55 GHz. The substrate used is the FR4 one having a relative dielectric permittivity of 4.4.

Because the substrate thickness of the proposed design will be variable, it is very important and before any other design calculations to determine the allowable range of ariation of this parameter. The upper value of the thickness can be determined from the following relationship [19], [20].

$$h \leq \frac{0.3c}{2\pi f\sqrt{\varepsilon_r}} \quad (1)$$

In the previous equation, the variable c is the speed of the light, f is the resonance frequency, ε_r is the relative permittivity of the substrate and h is the thickness. For the chosen frequency and permittivity, h must not exceed 1.95 mm.

While the thickness h of a FR4 standard box substrate is 1.6 mm, h here is varying from h1=1.5 mm to h2 = 2.1 mm between the two edges of the substrate wedge of 60 mm of length. In this way the upper edge of the patch has a thickness h of 1.9 mm. Note that the width of the substrate wedge is also of 60 mm. Accordingly and as shown in figure 2, the height (z) of the substrate is varying as a function of the depth (y) with the following equation:

$$z = 0.01y + 1.8 \quad (2)$$

Retrieval Number: 100.1/ijitee.H991613080724
DOI: 10.35940/ijitee.H9916.13080724
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

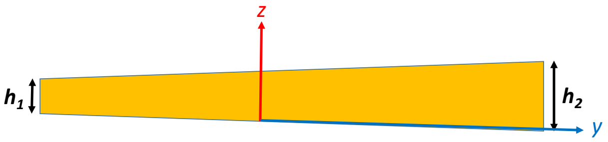

Fig. 2. Side view of the Wedge-Shaped Substrate Used in this Study

The width of the radiating element is determined based on the following relationship where c is the light velocity, f_r is the resonance frequency and ε_r is the relative permittivity[21, 22]:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{3}$$

Then the effective length of the patch is determined based on the following equation [23, 24]:

$$L_e = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \tag{4}$$

Where the effective relative permittivity is defined by the following relationship [25, 26]:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2\sqrt{1+12\frac{h}{W}}} \tag{5}$$

At last, the length of the patch is optimized based on the following relationship.

$$L = L_e - 2\Delta L \tag{6}$$

Where [27, 28] $\Delta L = \frac{0.412h(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)}$ (7)

The length L and the width W of the patch element are calculated to be respectively 20 mm and 26 mm. For these dimensions of the patch, its edge impedance is 264 Ohms.

The patch is related to the port of excitation via a microstrip transmission line as shown in Fig.3. In order to obtain a 50 Ω transmission line, the width of this line w0 is calculated to be 3.08 mm. Note that here the line is not connected simply to the patch because of the mismatching between the impedance of the line and the edge impedance of the patch. The technique of Inset feed line is used in this design as an alternative to allow the line to meet the patch at a depth where the impedance of the patch is equal to the impedance of the line. In fact, the input impedance decrease as we go from the edge of the patch to its center. Figures 3 shows a top view of the patch antenna with its feed line.

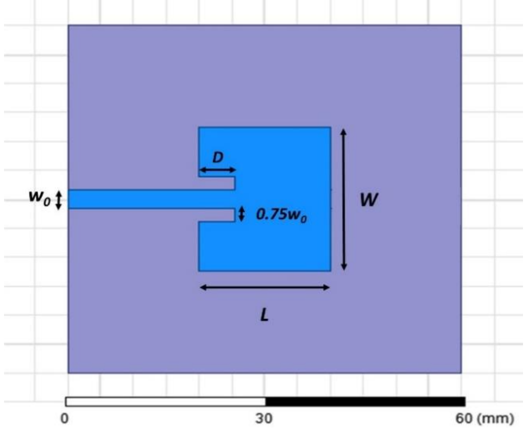

Fig. 3. Top View of the Wedge-Shaped Substrate Square Patch Antenna

The necessary depth D in the patch to obtain 50 Ω impedance is calculated to be 5.4 mm. The notch width which is the spacing between the line and the patch is also calculated to be 0.75 w_0.

III. RESULTS AND DISCUSSION

Before presenting the simulation results, a theoretical determination of the bandwidth as a function of the substrate thickness is necessary in order to serve as a reference for the simulations. Based on the dimensions of the proposed antenna and using the following relationship [29]:

$$BW = 3.771\left[\frac{\varepsilon_r-1}{(\varepsilon_r)^2}\right]\cdot\frac{h}{\lambda_0}\cdot\left(\frac{W}{L}\right) \tag{8}$$

The theoretical bandwidth for the proposed design is about 11% for a substrate thickness of 1.6 mm and is about 13% for a thickness of 1.9 mm. Note that λ_0 in the previous equation is the wavelength.

The design presented in the previous section is simulated in the electromagnetic radiation software HFSS. Figures 4 shows an overview of the designed antenna.

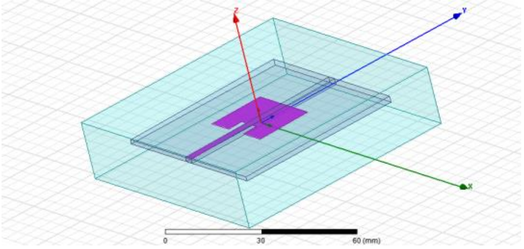

Fig. 4. Wedge Shaped Substrate Square Patch Antenna Design

In this section, the simulation results in terms of return loss, bandwidth and gain of this design will be compared to a standard box substrate design of same dimensions. Figure 5 shows a superposition of the variation of the return loss for both design between 2.5 GHz and 4.5 GHz. The simulated resonant frequency of the box based design is 3.55 GHz with a minimum return loss of -23.05 dB and the -10 dB bandwidth is 109.5 MHz. On the other hand, the simulated resonant frequency of the wedge based design is 3.53 GHz with a minimum return loss of -20.76 dB and the -10 dB bandwidth is 114.1 MHz.

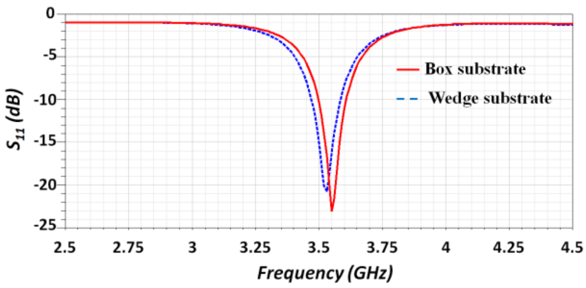

Fig. 5. Simulated Bandwidth and Return Loss for Box and Wedge Substrate Designs

Figure 6 shows a superposition of the variation of the antenna gain as a function of the angle θ. The maximum gain is obtained for θ=0 and this is true for both design. The maximum gain for the box based design is 1.9009 while the maximum gain for the wedge based design is 2.067.

To summarize, the wedge based design presents an enhancement of 4.2 % in terms of bandwidth and an enhancement of 8.74 % in terms of radiation gain. These enhancements are obtained to the detriment of the return loss because of a loss of 2.3 dB in the wedge based design with respect to the standard box based design.

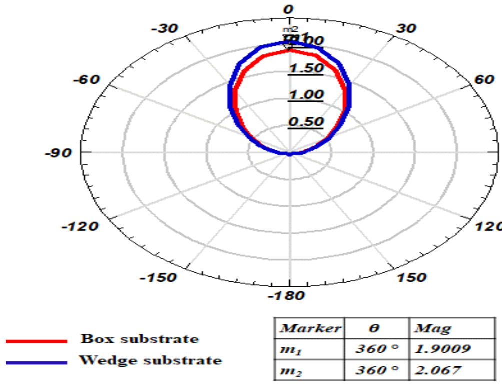

Fig. 6. Simulated Radiation Pattern for Box and Wedge Designs

IV. TRAPEZIUM INSET FEED LINE

The characteristic impedance Z_0 of a microstrip line is inversely proportional to the ratio W/H where W is the width of the line and H is the height or thickness of the substrate. According to Bahl and Trivedi [30], the expression of the characteristic impedance Z_0 of a microstrip line when W/H > 1 is :

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_e}\left(\frac{W}{H}+1.393+\frac{2}{3}\ln\left(\frac{W}{H}+1.444\right)\right)} \tag{9}$$

Where $\varepsilon_e = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+12\left(\frac{H}{W}\right)\right)^{\frac{-1}{2}}$ (10)

The above equations show that a change in the height which means the thickness of a microstrip line change the characteristic impedance of the line which in his turn change the return loss or the reflection coefficient of the line. That is why, in order to make the thickness variable while not affecting the characteristic impedance, the width of this line must be changing with the same linear slope of changing the thickness and in this way the fraction W/H remains constant. This principle is the base of the solution proposed in this section in order to correct the degradation of the wedge based design in terms of return loss. Thus the rectangular feed line of the previous section is replaced this time by a trapezium one as shown in the figure 7. Calculations are made in order to maintain an impedance of 50 Ω along the entire of the line. For this design the width of the line start at w_{0S} = 2.89 mm at the level of the port and ends at w_{0L} =3.38 mm at the level of the intersection with the patch.

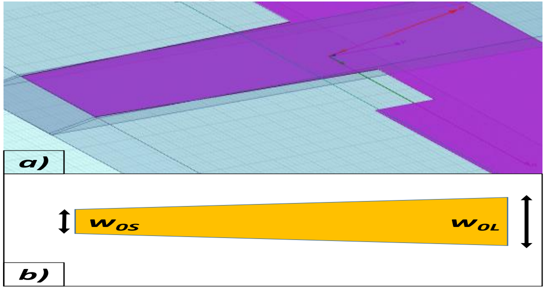

Fig.7. Modification in the Inset Feed Line: (A) Overview of the New Hfss Model, (B) New Trapezium Feed Line Dimensions

Figure 8 shows the spectacular correction of the return loss using this technique with a minimum simulated return loss of -24.12 dB at a resonant frequency of 3.54 GHz. The -10 dB bandwidth with this technique is 120.8 MHz Figure 9 shows a superposition of the variation of the antenna gain as a function of the angle θ for both design. The maximum gain for the wedge based design this time is 2.0735. To summarize, the design with a trapezium feed line associated to a wedge substrate presents an enhancement of 10.3 % in terms of bandwidth which is very close to the theoretical result presented at the beginning of the previous section and an enhancement of 9.07 % in terms of radiation gain. At the same time the return loss is not degraded. On the contrary it is much better.

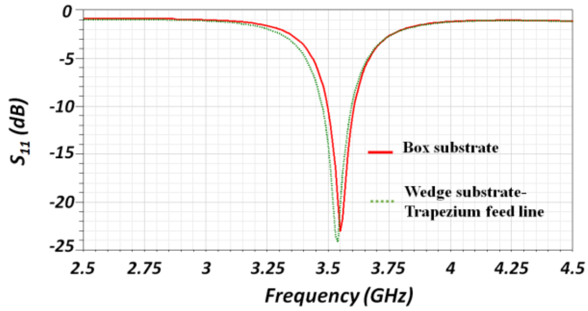

Fig. 8. Simulated Bandwidth and Return Loss for Box and Wedge-Substrate-Trapezium Feed Line Designs

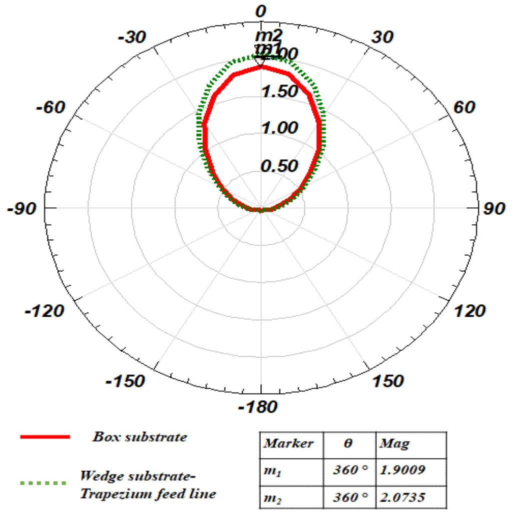

Fig. 9. Simulated Radiation Pattern for Box and Wedge-Substrate-Trapezium Feed Line Designs

Figure 10 shows that the radiation beam width is exactly the same in both versions of the antenna the box substrate based one and the wedge substrate based one. Both have a standard microstrip antenna angular width of 84° in the E plane. This means that the beam width of the proposed wedge-based antenna is not affected despite the fact that the elevation angle is significantly modified due to its design nature. Figure 11 shows the three dimensional radiation pattern of the proposed antenna.

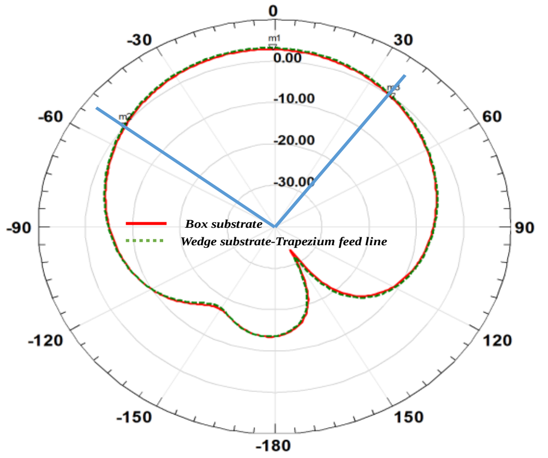

Fig. 10. Simulated 3 dB Angular Width for Box and Wedge-Substrate-Trapezium Feed Line Designs

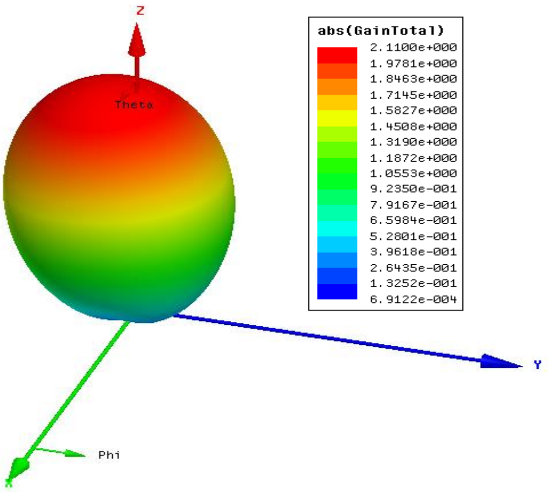

Fig. 11. The three-dimensional (3D) View Of Radiation Pattern For The Proposed 5g Antenna Model

Figure 12 shows the current distribution of both antennas. The current should be minimum at the edges of the antenna with a maximum of voltage and this is reproduced at the middle of the wave at the level of the feed line. It can be observed that the current distribution is almost the same in both antennas which means that the current distribution is not affected by the symmetry modification in the proposed wedge-based antenna.

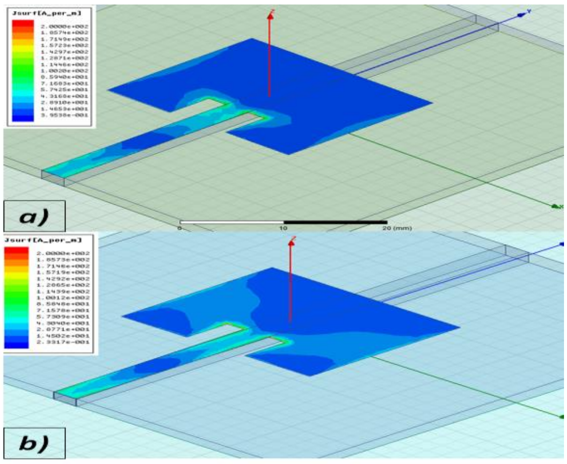

Fig. 12. Simulated Current Distribution for (a): box and (b): Wedge-Substrate-Trapezium Feed Line Designs

V. CONCLUSION

This paper presented a new design approach of microstrip antenna. In this design the box standard substrate is replaced by a wedge shaped substrate associated to a trapezium feed line instead of rectangular one. The results obtained in terms of return loss, bandwidth and radiation gain are very promising and validate the approach. The FR4 wedge substrate based proposed design of 6 mm linear thickness slope enhance the radiation by 9% and the bandwidth by 10.3 % while not degrading the return loss with respect to a standard box substrate based antenna design of the same dimensions. These results are encouraging and can be a source of further investigation or even an attempt at realization and measurement. At the end, the design approach presented in this study is completely new which prevents its comparison with similar works. At the same time, this design approach is fully combinable to the others design approaches such as new MPA planar geometries in order to obtain better results.

DECLARATION STATEMENT

Funding	No, I did not receive.
Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material	Not relevant.
Authors Contributions	All authors have equal participation in this article.

REFERENCES

1. J. G. Andrews et al., "What Will 5G Be?" in IEEE Journal on Selected Areas in Communications, vol. 32, no. 6, pp. 1065-1082, June 2014, doi: 10.1109/JSAC.2014.2328098. https://doi.org/10.1109/JSAC.2014.2328098
2. W. Roh et al., "Millimeter-wave beamforming as an enabling technology for 5G cellular communications: theoretical feasibility and prototype results," in IEEE Communications Magazine, vol. 52, no. 2, pp. 106-113, February 2014, doi: 10.1109/MCOM.2014.6736750. https://doi.org/10.1109/MCOM.2014.6736750
3. Przesmycki, R., Bugaj, M., & Nowosielski, “Broadband microstrip antenna for 5g wireless systems operating at 28 ghz”, Electronics (Switzerland), 2021 10(1), 1–19. https://doi.org/10.3390/electronics10010001. https://doi.org/10.3390/electronics10010001
4. R.E. Munson, “Conformal Microstrip antennas and microstrip phased arrays”, IEEE Trans Antennas propagation, Vol. 22, pp. 74-78, 1974, doi: 10.1109/TAP.1974.1140723. https://doi.org/10.1109/TAP.1974.1140723
5. R. Garg, “Progress in Microstrip antennas”, FIETE Technical Review, Vol. 18, No.2-3, pp 85-98, 2001.
6. B. Tütüncü, "Microstrip Antenna for 5G Communication: Design and Performance Analysis," 2020 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA), Ankara, Turkey, 2020, pp. 1-4, doi: 10.1109/HORA49412.2020.9152855. https://doi.org/10.1109/HORA49412.2020.9152855
7. Balti, E., & Johnson, B. K., “Sub-6 GHz Microstrip Antenna: Design and Radiation Modeling”, IEEE Transactions on Antennas and Propagation, January 2019, doi.org/10.48550/arXiv.1901.0525
8. B. Tütüncü, “Compact low radar crosssection microstrip patch antenna using particle swarm optimization”, Microwave and Optical Technology Letters 2019, 61(10), 2288-2294.

9. R. Kiruthika and T. Shanmuganantham, "Comparison of different shapes in microstrip patch antenna for X-band applications," 2016 International Conference on Emerging Technological Trends (ICETT), Kollam, India. 2016, pp. 1-6, doi: 10.1109/ICETT.2016.7873722. https://doi.org/10.1109/ICETT.2016.7873722
10. S. Sinan Gültekin , "A Comparison of Different Patch Geometry Effects on Bandwidth", September 2016, International Journal of Applied Mathematics, Electronics and Computers ISSN: 2147-822821
11. J. Lal and H. K. Kan, "Cross-shaped shorted patch antenna," 2005 Asia-Pacific Microwave Conference Proceedings, Suzhou, China, 2005, pp. 4 pp.-, doi: 10.1109/APMC.2005.1606572. https://doi.org/10.1109/APMC.2005.1606572
12. K. Bouzakraoui , "Patch Antenna Using Z-Slot for Bandwidth Improvement for 5G Network Applications", International journal of microwave and optical technology, vol.13, No.4, July 2018.
13. Saad Hassan Kiani, Khalid Mahmood, Umar Farooq Khattak, Burhan-Ud-Din and Mehre Munir, "U Patch Antenna using Variable Substrates for Wireless Communication Systems" International Journal of Advanced Computer Science and Applications(IJACSA), 7(12),2016. http://dx.doi.org/10.14569/IJACSA.2016.071237 https://doi.org/10.14569/IJACSA.2016.071237
14. D. Sabale , "Design of 'V' Shape Microstrip Patch Antenna", International Journal of Innovative Research in Computer and Communication Engineering, Vol. 3, Issue 3, March 2015.
15. R. Mishra, "Effect of Height of the Substrate and Width of the Patch on the Performance Characteristics of Microstrip Antenna", International Journal of Electrical and Computer Engineering (IJECE) Vol. 5, No. 6, December 2015, pp. 1441~1445 ISSN: 2088-8708, DOI: http://doi.org/10.11591/ijece.v5i6.pp1441-1445 https://doi.org/10.11591/ijece.v5i6.pp1441-1445
16. R. Toma , "Analysis the effect of Changing Height of the Substrate of Square Shaped Microstrip Patch Antenna on the Performance for 5G Application", I.J. Wireless and Microwave Technologies, 2019, 3, 33-45, DOI: 10.5815/ijwmt.2019.03.04. https://doi.org/10.5815/ijwmt.2019.03.04
17. R.K. Mishra , "Resonant frequency of wedge shaped microstrip antenna", Electronics letters, June 1990, vol. 26 No 13. DOI: 10.1049/el:19900596. https://doi.org/10.1049/el:19900596
18. A. Elrashidi ,"Performance Analysis of a Microstrip Printed Antenna Conformed on Cylindrical Body at Resonance Frequency 4.6 GHz for TM01 Mode", 9th International Conference on Mobile Web Information Systems, Procedia Computer Science 10 (2012) 775 – 784. https://doi.org/10.1016/j.procs.2012.06.099 https://doi.org/10.1016/j.procs.2012.06.099
19. Sridevi, S.; Mahendran, K. Design of Millimeter Wave Microstrip Patch Antenna for MIMO Communication. Int. Res. J. Eng. Technol. 2017, 4, 1513–1518.
20. Johari, S.; Jalil, M.A.; Ibrahim, S.I.; Mohammad, M.N.; Hassan, N. 28 GHz Microstrip Patch Antennas for Future 5G. J. Eng. Sci. Res. 2018, 2, 1–6.
21. Mungur, D.; Duraikannan, S. Microstrip Patch Antenna at 28 GHz for 5G Applications. J. Sci. Technol. Eng. Manag. Adv. Res. Innov. 2018, 1, 5–7.
22. Ahmed, Z.; McEvoy, P.; Ammann, M.J. Comparison of Grid Array and Microstrip Patch Array Antennas at 28 GHz. In Proceedings of the 2018 IEEE MTT-S International Microwave Workshop Series on 5G Hardware and System Technologies (IMWS-5G), Dublin, Ireland, 30–31 August 2018; pp. 1–3. [CrossRef]
23. Kaeib, A.F.; Shebani, N.M.; Zarek, A.R. Design and Analysis of a Slotted Microstrip Antenna for 5G Communication Networks at 28 GHz. In Proceedings of the 2019 19th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA); Institute of Electrical and Electronics Engineers (IEEE), Sousse, Tunisia, 24–26 March 2019; pp. 648–653.
24. Kiran, T.; Mounisha, N.; Mythily, C.; Akhil, D.; Phani Kumar, T.V.B. Design of microstrip patch antenna for 5G applications. IOSR J. Electron. Commun. Eng. (IOSR-JECE) 2018, 13, 14–17.
25. Teresa, P.M.; Umamaheswari, G. Compact Slotted Microstrip Antenna for 5G Applications Operating at 28 GHz. IETE J. Res. 2020, 1–8. [CrossRef].
26. Darboe, O.; Bernard, D.; Konditi, O.; Manene, F. A 28GHz rectangular microstrip patch antenna for 5G applications. Int. J. Appl. Eng. Res. 2019, 12, 854–857.
27. Khraisat, Y.S.H. Increasing Microstrip Patch Antenna Bandwidth by Inserting Ground Slots. J. Electromagn. Anal. Appl. 2018, 10, 1–11. [CrossRef].
28. Muhammad, S.; Shehu, Y.; Ya'u, I.; Abubakar, A.S. Design of Single Feed Dual-Band Millimeter Wave Antenna for Future 5G Wireless Applications. Sci. World J. 2019, 14, 84–87.
29. Przesmycki, R., Bugaj, M., & Nowosielski, L. (2021). Broadband microstrip antenna for 5g wireless systems operating at 28 ghz. Electronics (Switzerland), 10(1), 1–19. https://doi.org/10.3390/electronics10010001 https://doi.org/10.3390/electronics10010001
30. I. J. Bahl and D. K. Trivedi, "A Designer's Guide to Microstrip Line", Microwaves, May 1977, pp. 174.
31. Panda, S., Kumar, G. S., Sankeerthana, P., & Acharya, B. (2019). An Extensive Judgment of Rectangular Microstrip Patch Antenna with Flexible Substrates. In International Journal of Recent Technology and Engineering (IJRTE) (Vol. 8, Issue 2, pp. 4997–5001). https://doi.org/10.35940/ijrte.b1077.078219
32. Jain, P., & Singh, S. K. (2019). A Microstrip Patch Antenna with Defected Ground Structure (DGS) for WiMAX and WLAN Applications. In International Journal of Engineering and Advanced Technology (Vol. 9, Issue 1, pp. 6547–6550). https://doi.org/10.35940/ijeat.a1733.109119
33. Performance Enhancement of Rectangular Microstrip Antenna with Different Substrate Materials. (2019). In International Journal of Innovative Technology and Exploring Engineering (Vol. 9, Issue 2S, pp. 577–584). https://doi.org/10.35940/ijitee.b1065.1292s19

AUTHORS PROFILE

Mouhamad Abou Chahine received Ph.D. degrees in High Frequency Devices and Circuits–Electronic and Optoelectronic from 'Université de Limoges', Limoges, in 2009. Currently, he is an Assistant Professor at the Department of Electrical Engineering, ECAM-EPMI school of engineering. His research interests include renewable energy, power generation, power grids, high frequency electronics Electronic circuits and systems in IC technology for UWB applications. wideband Time Domain characterization of RF and microwave nonlinear components. Near -Field Electromagnetic radiation of RF microstrip circuits.

Mohamad Arnaout received his M.S. in Electrical and Electronics from the Lebanese University, Beirut, Lebanon, in 2007, his M.E. in Microelectronics and Electrical Engineering from Paul Sabatier, Toulouse, France, in 2008, and his Ph.D. in Electrical Engineering from the University of Paul Sabatier, Toulouse, France, in 2011. He is an associate professor and chairperson of the Electrical and Electronics Engineering Department of the International University of Beirut, Beirut, Lebanon. Dr. Arnaout is an IEEE member in dielectric and power societies since 2013 and currently he is the Chair of the IEEE - Lebanon Joint Chapter, IE13/PE31/CAS04/PEL35. His research interests include the electrostatic discharge, fault analysis, development of electric power system tools, and electric vehicles.

Fatma Tangour (Non-member) received Ph.D. degrees in Electrical Engineering, speciality Automatic and Industrial computing from 'Ecole centrale de Lille 'in 2007. Currently, she is Assistant Professor at the Department of Electrical Engineering of ECAM-EPMI, engineering school. Her Research include: optimization, predictive and reactive scheduling, control of production systems, collaboration between cyber physical production and energy systems, artificial intelligence, embedded systems, optimization and control algorithms for discrete event systems.

Mohamad Y. Abou Shahine is an assistant professor in the department of Electrical and Electronics Engineering at the Lebanese International University (LIU). He was born in Manara, West Bekaa, Lebanon. He received his B.E. degree in Communications and Electronics Engineering from Beirut Arab University (BAU) in July 2010.

In December 2015, he received his PhD degree in Electrical and Computer Engineering from AUB, with concentration on Applied Electromagnetics, RF Systems, and Communications Engineering. In February 2016, he has been offered a teaching position at the Lebanese International University (LIU) and he started his work as an assistant professor in the school of Engineering. His research interests include the design of antennas, power amplifiers, filters, wireless communications networks in addition to investigating the efficiency of PV systems.