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Design of a Compact Dual-Frequency Microstrip Antenna using DGS Structure for Millimeter-Wave Applications

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ABSTRACT

In this paper, a Millimeter-wave (MMW) antenna has been proposed for a current and future wireless application. The proposed model has two resonances at 30.5 GHz and 52.4 GHz. The proposed model has been designed and optimized using a commercial electromagnetic simulator (CST-Studio) and focused on attaining a return loss rate that is lower than -10 dB. The proposed MMW models are built on a small thick Rogers Substrate (RT-5880) with h = 0.508 mm for the thickness, relative permittivity of εr = 2.2, and tanδ = 0.0009 for the loss tangent, while the substrate has a width w_s equal to 6 mm and a length l_s equal to 6 mm. The design process of the model came at three steps, the first step after mathematical calculations has an output of model which has feeding port of 50 ohm with a feedline base length l_b of 0.5 mm and a feedline length l_f of 3 mm, the second step was by using the tapering techniques for enhancing matched impedance after initial calculations to have a length of tapering l_t equal to 1.8 mm, then finally extracting four corner slots to the patch for creating the final proposed model. The previous design process is to assure reliability, mobility, and high efficiency for the proposed antenna. The advantages of this model are the small size, low profile, low fabrication cost, and straightforward design structure. The proposed design can be employed for a variety of Millimeter-wave applications like wireless personal area network (WPAN) and 5G application in some countries like Colombia and Mexico. The proposed model has a moderate gain of 3 dBi to 7 dBi at resonance frequencies of 30.5 GHz and 52.4 GHz, which is one of the unique characteristics of the proposed antenna. The impedance bandwidth is between 28.7 Ghz and 32.6 GHz, which is equal 3.9 GHz, and 49.7 GHz to 56.2 GHz, which is equal to 6.5 GHz respectively for the proposed model, and satisfying efficiency of about 75% and 87% as calculated by CST -Studio, and a VSWR is equal to 1, All of these positive results are more than enough to satisfy the needs of millimeter-wave wireless applications.

1. Introduction

Microstrip patch antenna for Millimeter-wave (MMW) communication systems has paid notable attention for meeting many requirements for present and future applications. These applications are

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represented by radars, security scanners, short-range wireless networks, higher band 5G networks, and many other applications.

Compared to conventional 2.4 GHz or 5 GHz bands, the millimetre wave license-free bands have unique features. These features place the suggested design at the top of the market for high bandwidth commercial wireless networks [1]. Countries all over the world have taken note of the 60GHz radio license-free since it has shown to be valuable and high-quality [1-3].

Moreover, depending on the magnitude (5-30 dB/km) of the carrier frequency, the atmospheric conditions, and common building materials [4–5], the signal can withstand an attenuation level of up to 20 dB in free space. There are several emerging 60 GHz standards, such as Wireless HD [6], the IEEE multi-gigabit mm wave 802.15.3c standards [6-7], and the standard ECMA-387 for high rate 60 GHz [8-9], that are popular for short-range wireless personal area networking (WPAN).

For Millimeter-wave applications like radars, security scanners, short-range wireless networks, higher band 5G networks, there is a need for a small antenna size with a wideband and better antenna beam forming to achieve the needs of the Millimeter-wave applications wireless personal area network (WPAN) [1] and 5G application in some countries like Colombia and Mexico, which is planned for licensed use [10]. Therefore, the planar multiband antenna structures microstrip (MS), coplanar waveguide (CPW), and stripline (SL) have become very popular antennas due to their compact sizes, low cost, less weight, and ease of installation with the current microwave wireless devices as compared to the conventional wire antennas (helical, yagi-Uda and spiral) [11-18].

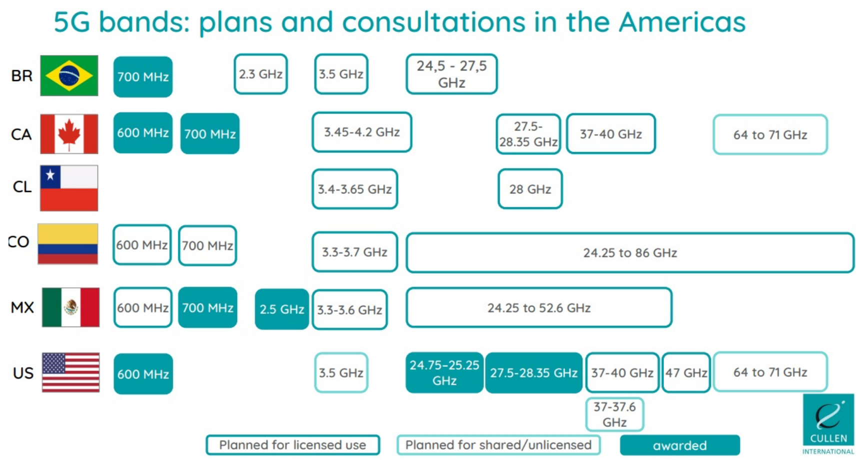


Fig. 1. 5G bands: plans and consultations in the Americas - ITU workshop - September 2019 [10]

Also, plenty of interest has been received in designing an efficient microstrip patch antenna module to achieve the desired characteristics within the effective operating frequency of MMW systems [11-13]. In addition, the microstrip antenna configuration has superior advantages over the other planar structures of antennas, including easy fabrication and excellent compatibility with modern microwave circuits [11].

A substrate is sandwiched between two copper metal sheets, one of which is grounded, to create patch antennas. The patch's dimensions can be rectangular, triangular, circular, and so on, each with unique transmission characteristics, depending on the necessity. To boost gain and aid in the production of dipoles, specific cut-out shapes can also be included. The addition of parasitic sections can further increase directivity. Based on the height and dielectric constant of the substrate, different substrates can also alter how the patch functions. To meet specifications, each patch antenna component must be carefully picked [19,20].

The design of the dual frequency microstrip patch antenna, which resonates at 30.5 GHz and 52.4 GHz, is presented in this study. There are various shapes available for the patches, like elliptical, square, pentagonal, octagonal, circular ring, rectangular, etc. The rectangular form was selected because it has more benefits than other microstrip designs [21,22]. It is simple to perform fabrication analysis and performance prediction.

The proposed model has a rectangular shape with four edge slots in the patch's corners, this model also has a Defected Ground Structure (DGS), which is made up of an elliptical-shaped slot in the ground. In microstrip antennas, DGS and slots is used for the enhancement of gain and bandwidth, as a common example, they used some slots in the patch radiators [14]. Also, it has been used for higher mode harmonic suppression, mutual coupling between elements, and to improve the characteristics of the microstrip antenna radiation [23]. By etching a slit in the ground and the patch of Microstrip antenna with the right length and width, it is possible to reduce the size of the antenna and increase bandwidth. Changing the current distribution on the ground because of the DGS is for improving the gain and the bandwidth of the proposed microstrip patch antenna. The model resonates at a dual band of frequencies of 30.5 GHz and 52.4 GHz with a fractional bandwidth of 12.7% and 12%, respectively, with a gain of 3.8 dBi, and 6.6 dBi, the efficiency is 75%, and 87% as calculated by CST -Studio, while VSWR approximately equal to 1, all the previous results of the proposed model are high and acceptable with respect to the compactness of the model. In addition, the presented results are acceptable after comparison with the researchers' previous works [32-37].

In general, Antennas with wide beam widths typically have low gain and antennas with narrow beam widths tend to have higher gain, so low gain and narrow bandwidth are the main limitations of microstrip patch antennas [30]. So, some techniques are presented in designing microstrip patches, such as tapering techniques and DGS, to overcome these limitations.

The challenges of bandwidth against gain, efficiency, and compact size is handled in this design, resulting in approved bandwidth combined with a good gain in this bandwidth as well as the antenna's small size, which is smaller than conventional patch antennas like the ones which are proposed at [12] and [31].

The structure of this article is as follows, the design process of the suggested model with specific analytical parameters to create a high-performance antenna is presented in Section 2. The proposed antenna design is provided in Section 3 along with comprehensive antenna geometry. The simulation and results are displayed in Section 4. Then the conclusion follows that.

2. Design Methodology

The commercial electromagnetic simulator (CST-Studio) was used for antenna parameter design and analysis. This simulation software will be used to display the analysis results in this study.

The size extension method, which exits the antenna with one of its higher order transverse electromagnetic modes whose characteristics nearly match those of the fundamental mode, is used to determine the patch antenna's dimensions. By selecting the dielectric constant ε_r, the length l_p and width w_p of the expanded patch antenna can be represented [15].

The width of the patch w_p can be determined using the equation as: (1)

$$w_p = \frac{c}{2f_r} X \sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

where,
w_p = width of the patch.
c = speed of light ($3*10^8$ m/s).
f_r = resonant frequency.
ε_r= Dielectric constant of substrate.

The effective dielectric constant ε_{reff} is determined by: (2)

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1 + 12\frac{h}{W}]^{-0.5} \quad (2)$$

where,
ε_{reff} = effective dielectric constant.
h = thickness of substrate.
The length of the patch is calculated as: (3)

$$l_p = L_{eff} - 2\Delta L \quad (3)$$

where,
l_p = the physical length of the patch.
L_{eff} = the effective length or the distance between the radiating edge.
ΔL = fringing field.
The effective length L_{eff} is taken as: (4)

$$l_{eff} = \frac{c}{2f_r x\sqrt{\varepsilon_{reff}}} \quad (4)$$

The fringing ΔL is calculated as: (5)

$$\Delta L = 0.412\text{h}\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{\varepsilon_{reff}-0.258(\frac{W}{h}+0.8)} \quad (5)$$

The feed line impedance is calculated as: (6)

$$Z_0 = \frac{87}{\sqrt{\varepsilon_r+1.41}}\ln\left(\frac{5.98h}{(0.8\text{w}+\text{t})}\right) \quad (6)$$

where,
Z_0 = the matched impedance.
ε_r= ielectric constant of substrate.
h = dielectric thickness
w = the width of the feed line
t = thickness of the copper

3. Design of The Antenna

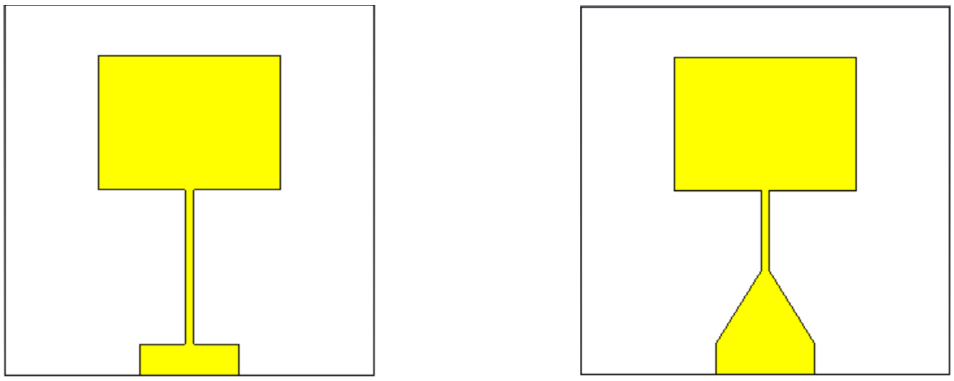
A substrate with a height of 0.508 mm from RT Duriod 5880 is used to simulate the suggested antenna design. The substrate is chosen due to its great performance, mechanical strength, light weight, and ease of supply.

Applying the antenna to resonate at the desired dual frequency, which is about equivalent to 30 GHz and 52 GHz, requires using equation (1) to determine the patch's width, which is equal to 3.2 mm, and equations (3), (4), and (5) to determine the patch's length, which is equal to 2.15 mm, the patch width and length are calculated using the previous equations in addition to the parametric study at the commercial electromagnetic simulator (CST-Studio) by sweeping between the values of patch width and length to reach the desired value, which allowed the presented model to resonate at the desired frequency.

The first design, after mathematical calculations, and after adjusting the width of feed line w_b of 1.613 to have a feeding port impedance Z_0 to be equal 50 ohm by using equation (6), and after parametric study by using the commercial electromagnetic simulator (CST-Studio) for the feedline base to have the proper feedline base length l_b of 0.5 mm and a feedline length l_f of 3 mm, is as shown in Fig. 2 (a).

Using the tapering techniques for enhancing matched impedance by gradually decrease the width of the feeding area to increase the matched impedance from 50 ohm for the feeding line to be near to the value of the matched impedance of the patch and this is by using equation (6) have a length of tapering l_t equal to 1.8 mm as shown in Fig. 2 (b), and this allow the design to resonate near to the desired frequency.

The final optimized design after final calculations using the previous equations and the commercial electromagnetic simulator (CST-Studio) to reach the optimum values for the basic proposed model is shown in Fig. 3 with an optimized taper length l_{to} of 2.8 mm, which is reached by using the same procedure as in the previous model of Fig. 2 (b) , and this design will be adapted to achieve the final proposed model.



(a) (b)

Fig. 2. (a) First design with adjusted 50 ohm feeding port, (b) second design with tapering feedline

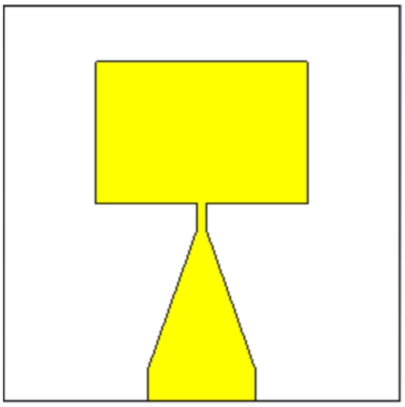


Fig. 3. The optimized design after final calculations

Before reaching the desired results of this work, two models were designed with the same main dimensions as the current proposed model, these two models are an initial step to reach the final results of the current proposed dual band model [32], except that the first model didn't have the DGS and the four edge slots as shown in Fig. 4, while the second model has the four edge slots with different slots' dimensions and without DGS as shown in Fig. 5.

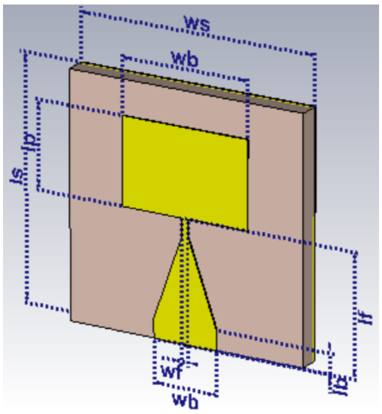


Fig. 4. First model without corner slots

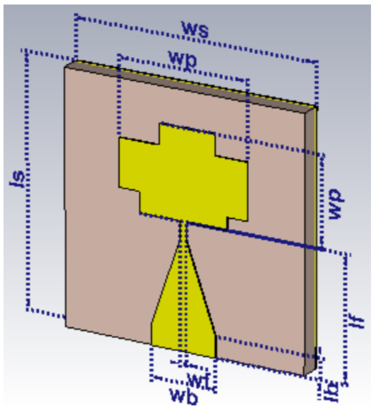


Fig. 5. Second model without DGS

The first previously proposed model covers a single frequency of 39.7 GHz with a gain of 6.6 dBi, an efficiency of 73.8%, a VSWR equal to 1, and a fractional bandwidth of 6.8%, while the second previously proposed model covers a single frequency 43 GHz with a gain of 6.6 dBi, efficiency of 78%, a VSWR equal to 1, and a fractional bandwidth equal to 7.2% [32].

Fig. 6, shows the first model after fabrication, and due to the compactness of the design, there were some difficulties in measurements because of lack of compatible connector to the compact design (the connector was wider than the width of the designed model), and because of these difficulties.

Fig. 6. First model after fabrication

According to Fig. 7, the suggested antenna comprises three layers, which are a ground layer, a dielectric layer, and a patch layer. Both the ground layer and the patch layer are comprised of copper as a conducting lossy material. After final optimization, the main proposed MMW patch antenna is depicted in isometric form in Fig. 7. The rectangular patch has a length of l_p and a width of w_p . It is designed on an RT5880 substrate with relative permittivity ε_r, loss tangent tanδ of value 0.0009, and thickness h. The substrate has a width w_s and a length l_s. The antenna is fed through a slot of length l_b and width w_b. The tapering of the transmission line has a length l_t to improve the matching of the impedance between the transmission line and the patch, which will improve bandwidth and gain respectively. At Fig. 7. There are four corner slots which added to the patch antenna after parametric study by using the commercial electromagnetic simulator (CST-Studio), these corner slots are to keep the size of the model small as possible with improvement of the bandwidth, gain and efficiency, also for shifting the resonant frequency to the desired values [33-34]. Fig. 8. Shows that the DGS, which is utilised to further improve gain, limited bandwidth of the proposed design, and impedance, so the purpose of DGS is to get a wider bandwidth with maintaining acceptable values of efficiency and return loss [35-37].

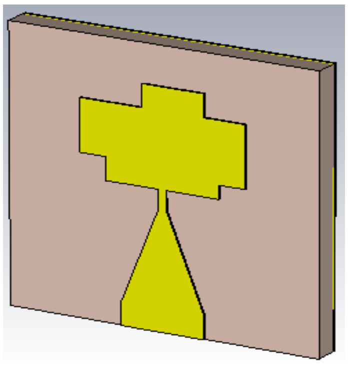


Fig. 7. proposed model isometric front view

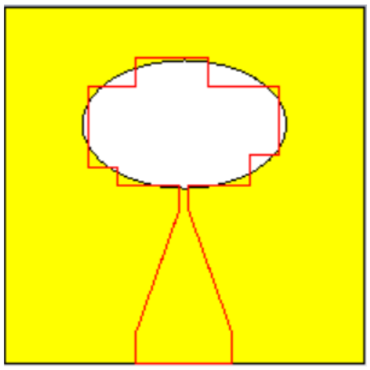


Fig. 8. proposed model back view.

The optimised desirable parameters for the model are provided in Table 1 after the optimization of the parameters was completed in the commercial electromagnetic simulator (CST-Studio) to acquire the desired frequencies.

Table 1
Antenna parameters

Symbol	Parameter	Dimensions
w_s	Substrate width, & ground width	6
l_s	Substrate length, & ground length	6
w_p	Width of patch	3.2
l_p	Length of patch	2.15
w_f	Feed Width	0.145
l_f	Feed Length	3
h	Substrate higth	0.508
ε_r	Dielectric Constant	2.2
w_b	Feedline base width	1.613
l_b	Feedline base length	0.5
l_t	Taper length before optimization	1.8
l_{to}	Taper length after optimization	2.8
t	Ground and patch thickness	0.035
w_{cpr}	Upper right slot width	0.8
w_{cpl}	Upper left slot width	1.2
l_{cpu}	Upper slot length	0.5
l_{cpr}	Lower right slot length	0.3
l_{cpl}	Lower left slot length	0.5
w_{cpll}	Lower slot width	0.5
R_u	U radius of DGS	3.4
R_v	V radius of DGS	2.2

For the current dual band proposed model, Fig. 9 shows the geometric view of the antenna, which has dimensions of 0.6 λ_o x 0.6 λ_o, while Fig. 10 shows the elliptical defected ground structure geometry and position.

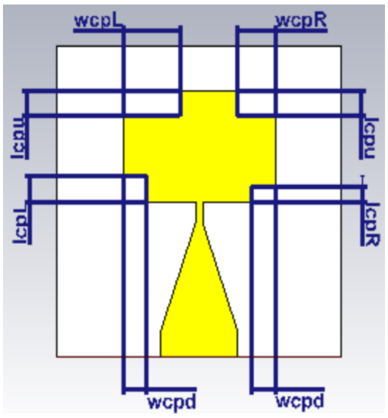


Fig. 9. Geometric view of the proposed patch antenna

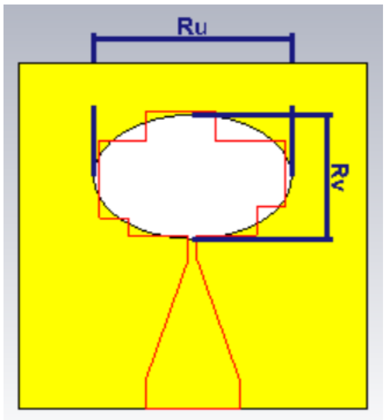


Fig. 10. Geometric view of the elliptical defected ground structure

4. Simulation and Results

The below results are measured by using the commercial electromagnetic simulator (CST-Studio) in which the calculated results are return loss, bandwidth, gain, efficiency, VSWR, current distribution, and radiation pattern.

Fig. 11 shows the return loss of the designs, which are shown in Fig. (2). Curves (a), and (b) show the return loss during the steps of optimization, and curve (c) shows the return loss after final optimization of the first initial model, while Fig. 12 shows the return loss of the first initial model and second initial model after adding the four edge slots.

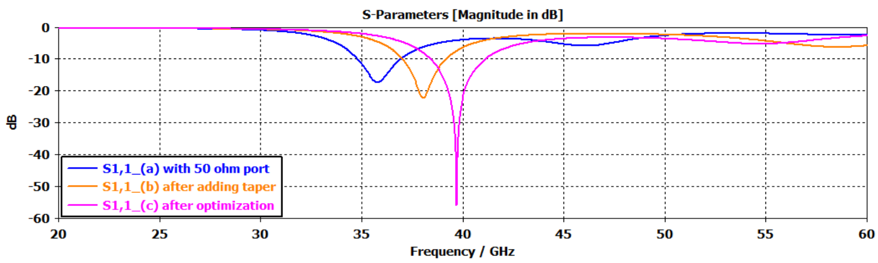


Fig. 11. Return loss of the initial designs

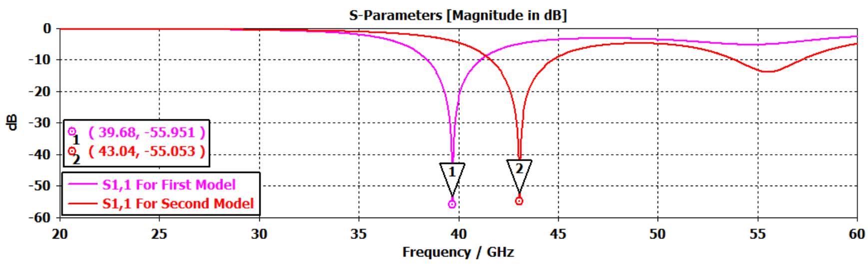
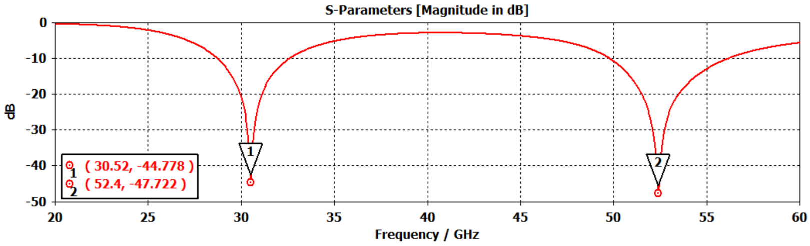
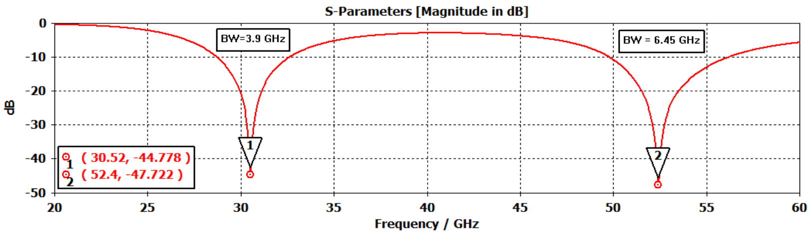


Fig. 12. Return loss of the first and second proposed models

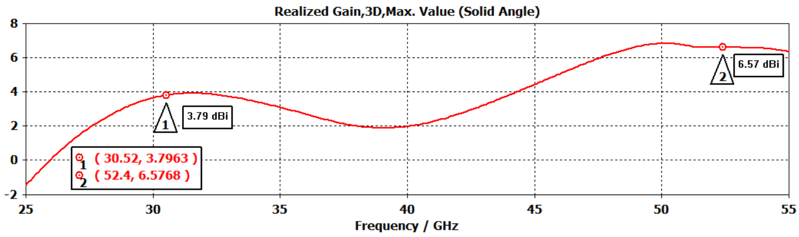
Figure 13 depicts the simulation results for the recently dual band proposed model, while Figs. 13 (a) and (b) depict the return loss and bandwidth of the suggested design. These values for the return loss are -44 dB and -47 dB, respectively. The proposed design achieves an adequate bandwidth between 28.7 GHz and 32.6 GHz, which is equal to 3.9 GHz for the first resonant frequency, and 49.7 GHz to 56.2 GHz, which is equal to 6.4 GHz for the second resonant frequency.



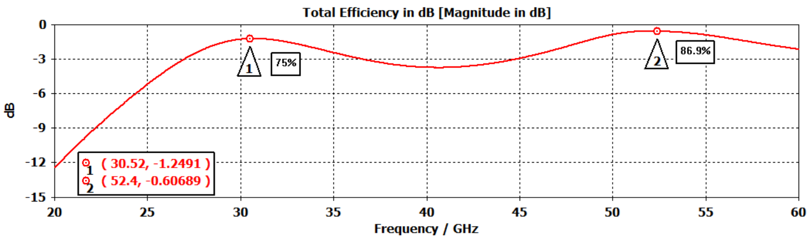
(a) Return loss for the proposed model



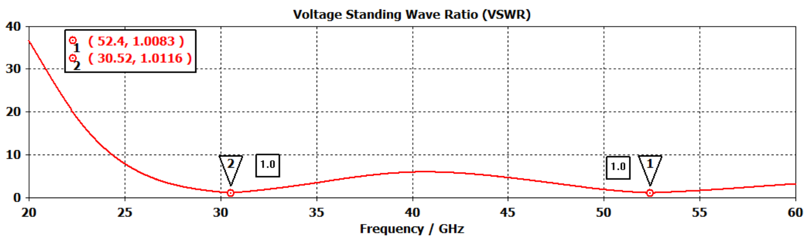
(b) Bandwidth for the proposed model



(c) Gain for the proposed model



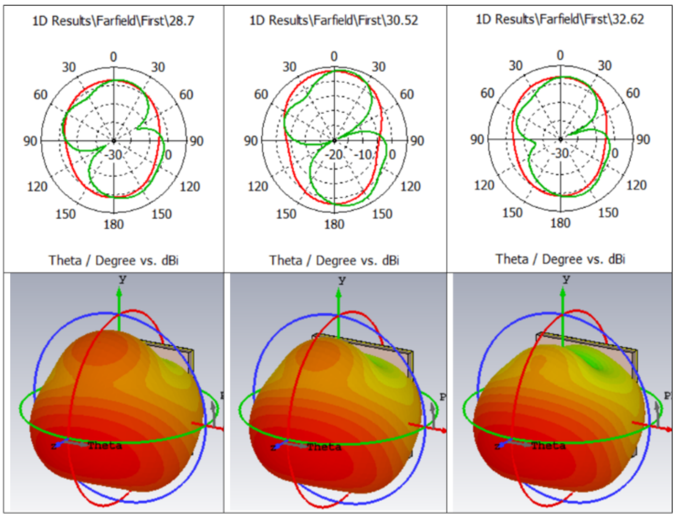
(d) Efficiency of the proposed model



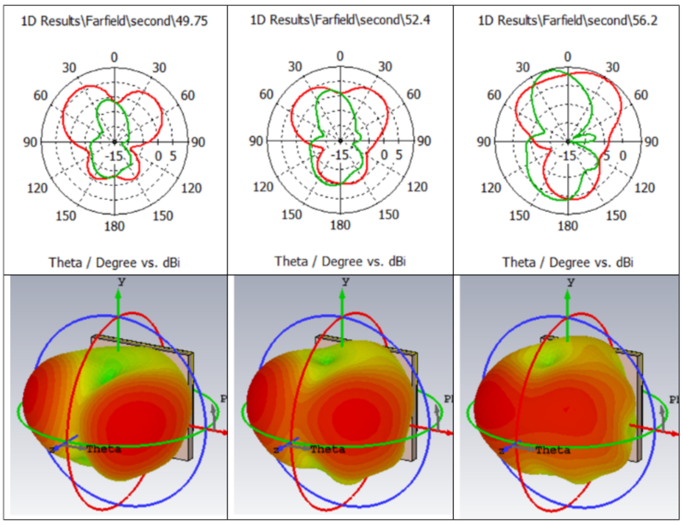
(e) VSWR of the proposed model

Fig. 13. Simulated results at CST

In Figure 13 (c), the suggested antenna offers a gain of 3.8 dBi for the first resonant frequency and 6.6 dBi for the second resonant frequency with a consistent directional radiation pattern. Figure 13 (d) shows a very sufficient efficiency of the proposed model, which is equal to 75% and 86.8%, respectively. Figure 13 (e) shows that the proposed design has an accurate optimal VSWR value of 1 at the resonant frequency of 30.5 GHz and 52.4 GHz. Figure 14 (a) depicts the suggested design's steady, uniform, omni-directional radiation pattern. Furthermore, it displays the 3D pattern of the suggested model as well as both situations of Phi 0 degree and Phi 90 degree.



(a) The proposed antenna's 30.5 GHz pattern



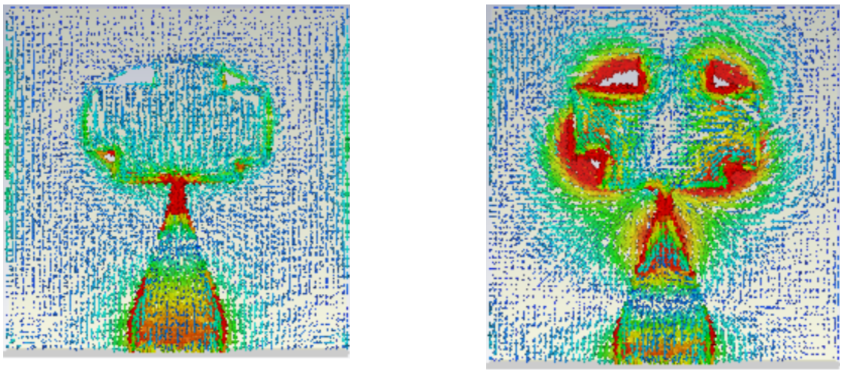
(b) the proposed antenna's 52.4 GHz pattern

Fig. 14. Polar and three-dimensional radiation pattern for the whole bandwidth of the proposed model.

Figure 14 (b) shows a uniform directional radiation pattern with very smooth radiation where all beams are equally in the same wide directional position, which indicates increasing spectral efficiency.

Generally, it can be seen clearly in both cases where Phi is 0 degrees and Phi is 90 degrees. The antenna exhibits a stable radiation pattern with no back and side lobes in the range of proposed targeted resonant frequencies.

The surface current distribution at 30.5 GHz is shown in Fig. 15 (a), while Fig. 15 (b) depicts the current distribution along the patch at 52.4 GHz. It can be seen that the current density is high on the feed line at both frequencies, while it can be seen on the outer edge of the rectangular patch antenna at frequency 52.4 GHz.



(a) (b)

Fig. 15. Current distribution along the patch (a) at 30.5 GHz, (b) at 52.4 GHz

5. Comparison with Other Related Works

Using the presented model for Millimeter-wave applications to highlight the advantages of it, a comparison between the proposed work with prior arts in terms of operational frequency band, physical dimension, bandwidth, radiation gain, efficiency, design complexity, and applications are shown in Table 3. In this work, the novelty of compactness of the design and high bandwidth is shown with respect to all compared models. Only [28] has smaller size by 1 mm but also has lower bandwidth and gain. For gain, the proposed model offers higher gain than [25,27], and [28]. The proposed antenna beats comparable models in terms of bandwidth, compactness, while it has acceptable high gain.

Table 2
Comparison with other related works

Ref.	Frequency	Dimensions mm	Bandwidth , [GHz]	Gain dBi	Efficiency	design complexity	application
[3]	33 46	12 x 18	1 1	7.83 6.4	NA	Easy	5G applications
[24]	57	11 x 11	10	8.6	NA	Easy	
[25]	28 50	11 x 8	1.5 12	2.6 NA	NA	Easy	5G applications
[26]	25 50	7 x 7	0.64 1.78	6.92 8.34	NA	Medium	MMW applications
[27]	60	8x 8	4	5.42	57	Easy	5G applications
[28]	30	5 x 5	2.5	5	NA	Medium	Ka- band applications
[29]	30	10 x 10	2	7.7	NA	Easy	MMW applications
This work	30.5 52.4	6 x 6	3.9 6.45	3.8 6.6	75 87	Easy	MMW applications

6. Conclusions

A dual frequency compact-sized MMW high-efficiency and high-gain microstrip patch antennas are presented. Using the RT Duriod 5880 substrate, the design and analysis of the model of microstrip patch antennas were simulated. A tapering fed line structure was designed to improve the matched impedance to enhance the gain, while using DGS for bandwidth, gain, and efficiency enhancement. The proposed model resonates at 30.5 GHz and 52.4 GHz with gain of 3.9 dBi and 6.6 dBi, respectively, which is suitable for Millimeter-wave applications in many countries like wireless personal area network (WPAN) and 5G application in some countries like Colombia and Mexico. The proposed model has an impedance bandwidth of 3.9 GHz and 6.5 GHz for both frequencies. A good agreement can be obtained due to the model's efficiency, which is around 75% and 87%, respectively for both resonance frequencies.

References

[1] Park, Cheolhee, and Theordore S. Rappaport. "Short-range wireless communications for next-generation networks: UWB, 60 GHz millimeter-wave WPAN, and ZigBee." *IEEE Wireless Communications* 14, no. 4 (2007): 70-78. https://doi.org/10.1109/MWC.2007.4300986

[2] Daniels, Robert C., and Robert W. Heath. "60 GHz wireless communications: Emerging requirements and design recommendations." *IEEE Vehicular technology magazine* 2, no. 3 (2007): 41-50. https://doi.org/10.1109/MVT.2008.915320

[3] Elsayed, Mohamed Sabry, Mohamed Fathy Abo Sree, and Mohamed Hassan Abd Elazeem. "A Dual Band Rectangular Patch Antenna for 5G Applications." In *2020 12th International Conference on Electrical Engineering (ICEENG)*, pp. 200-202. IEEE, 2020. https://doi.org/10.1109/ICEENG45378.2020.9171733

[4] Giannetti, Filippo, Marco Luise, and Ruggero Reggiannini. "Mobile and personal communications in the 60 GHz band: A survey." *Wireless Personal Communications* 10, no. 2 (1999): 207-243. https://doi.org/10.1023/A:1018308429332

[5] Anderson, Christopher Robert, and Theodore S. Rappaport. "In-building wideband partition loss measurements at 2.5 and 60 GHz." *IEEE transactions on wireless communications* 3, no. 3 (2004): 922-928. https://doi.org/10.1109/TWC.2004.826328

[6] Gupta, Abhishek Kumar, Hemant Gurung, Samerendra Nath Sur, and Rabindranath Bera. "BER performance of IEEE 802.11 ad for single carrier and multi carrier." *Int. J. Eng. Sci. Technol.* 1, no. 4 (2012): 2180-2187.

[7] “IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements. Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPANs) Amendment 2: Millimeter-wavebased Alternative Physical Layer Extension,” IEEE Std 802.15.3c-2009 (Amendment to IEEE Std 802.15.3-2003) , vol., no., pp. c1–187, Oct. 12, 2009.

[8] ECMA International, “High Rate 60 GHz Phy, MAC and HDMI PAL,” Standard ECMA-387, 1st Edition, Dec. 2008. [Online] Available: http://www.ecmainternational.org/publications/files/ ECMA-ST/Ecma-387.pdf

[9] Saini, Jyoti, and S. K. Agarwal. "Design a single band microstrip patch antenna at 60 GHz millimeter wave for 5G application." In *2017 international conference on Computer, Communications and Electronics (Comptelix)*, pp. 227-230. IEEE, 2017. https://doi.org/10.1109/COMPTELIX.2017.8003969

[10] I. workshop, “5g and spectrum: different approaches,” https: //www.itu.int/en/ITU-D/Regulatory-Market/Documents/Events2019/ Togo/5G-Ws/Ses4_Gomes-5Gspectrum-Assignments.pdf, 2019, iTU workshop: 5G and new technologies. Lome, Republic of Togo

[11] Ghouz, Hussein Hamed Mahmoud, Mohamed Fathy Abo Sree, and Muhammad Aly Ibrahim. "Novel wideband microstrip monopole antenna designs for WiFi/LTE/WiMax devices." *IEEE Access* 8 (2020): 9532-9539. https://doi.org/10.1109/ACCESS.2019.2963644

[12] Elsayed, Mohamed S., Mohamed F. AboSree, and Mohamed H. AbdElazem. "Compact wide band antenna for millimetric communications." In *IOP Conference Series: Materials Science and Engineering*, vol. 1051, no. 1, p. 012032. IOP Publishing, 2021. https://doi.org/10.1088/1757-899X/1051/1/012032

[13] Fatah, Sara Yehia Abdel, Ehab KIKI Hamad, Wael Swelam, A. M. M. A. Allam, Mohamed Fathy Abo Sree, and Hesham A. Mohamed. "Design and implementation of UWB slot-loaded printed antenna for microwave and millimeter wave applications." *IEEE Access* 9 (2021): 29555-29564. https://doi.org/10.1109/ACCESS.2021.3057941

[14] Sree, Mohamed Fathy Abo, Wael Swelam, Mohamed Hassan, and Hadia El-Hennawy. "An inverted f with dual frequency for radar & 5g applications above 85 ghz." In *2019 PhotonIcs & Electromagnetics Research Symposium-Spring (PIERS-Spring)*, pp. 4152-4160. IEEE, 2019. https://doi.org/10.1109/PIERS-Spring46901.2019.9017523
[15] Balanis, C. A., "Antenna Theory: Analysis and Design,"3rd Edition, JohnWiely & Sons Inc., New York, 2005.
[16] Kraus, J. D. and R. J. Marhefka, "Antennas for All Applications," John Wiely & Sons Inc., New York, 2002.
[17] KIN-LU WONG, "Broadband Microstrip Antennas," John Wiely & Sons Inc., 2002. https://doi.org/10.1002/0471221112
[18] Chen, Zhi Ning, and Michael Yan Wah Chia. *Broadband planar antennas: design and applications*. John Wiley & Sons, 2006. https://doi.org/10.1002/0470871768
[19] Kishore, Siddharth, and AR Abdul Rajak. "Microstrip Patch Antenna with C Slot for 5G Communication at 30 GHz." *Emerging Science Journal* 6, no. 6 (2022): 1315-1327. https://doi.org/10.28991/ESJ-2022-06-06-06
[20] Denlinger, Edgar J. "Radiation from microstrip resonators (correspondence)." *IEEE Transactions on microwave Theory and techniques* 17, no. 4 (1969): 235-236. https://doi.org/10.1109/TMTT.1969.1126937
[21] Al-hetar, Abdulaziz M., and Esmat AM Aqlan. "High performance & Compact Size Of Microstrip Antenna For 5G applications." In *2021 International Conference of Technology, Science and Administration (ICTSA)*, pp. 1-3. IEEE, 2021. https://doi.org/10.1109/ICTSA52017.2021.9406537
[22] Veerendra, K., G. Padma Ratna, and S. Nagakishore Bhavanam. "Design of Microstrip Patch Antenna with Parasitic Elements for Wideband Applications." (2019).
[23] Ullah, Shahid, Cunjun Ruan, Muhammad Shahzad Sadiq, Tanveer Ul Haq, Ayesha Kosar Fahad, and Wenlong He. "Super wide band, defected ground structure (DGS), and stepped meander line antenna for WLAN/ISM/WiMAX/UWB and other wireless communication applications." *Sensors* 20, no. 6 (2020): 1735. https://doi.org/10.3390/s20061735
[24] Jang, Tae Hwan, Hong Yi Kim, Dong Min Kang, Seung Hun Kim, and Chul Soon Park. "60 GHz low-profile, wideband dual-polarized U-slot coupled patch antenna with high isolation." *IEEE Transactions on Antennas and Propagation* 67, no. 7 (2019): 4453-4462. https://doi.org/10.1109/TAP.2019.2911623
[25] Kiran, T., N. Mounisha, Ch Mythily, D. Akhil, and TVB Phani Kumar. "Design of microstrip patch antenna for 5G applications." *IOSR J. Electron. Commun. Eng.(IOSR-JECE)* 13 (2018): 14-17.
[26] Awan, Wahaj Abbas, Abir Zaidi, Niamat Hussain, Samreen Khalid, and A. Baghdad. "Characterization of dual band MIMO antenna for 25 GHz and 50 GHz applications." In *2018 International Conference on Computing, Electronic and Electrical Engineering (ICE Cube)*, pp. 1-4. IEEE, 2018. https://doi.org/10.1109/ICECUBE.2018.8610982
[27] Saini, Jyoti, and S. K. Agarwal. "Design a single band microstrip patch antenna at 60 GHz millimeter wave for 5G application." In *2017 international conference on Computer, Communications and Electronics (Comptelix)*, pp. 227-230. IEEE, 2017. https://doi.org/10.1109/COMPTELIX.2017.8003969
[28] Rohrdantz, Benjamin, Thomas Jaschke, Frauke KH Gellersen, and Arne F. Jacob. "A dual-frequency and dual-polarized patch antenna at Ka-band." In *2015 European Radar Conference (EuRAD)*, pp. 473-476. IEEE, 2015. https://doi.org/10.1109/EuRAD.2015.7346340
[29] Zaidi, Abir, Abdennaceur Baghdad, Abdelhakim Ballouk, and Abdelmajid Badri. "Design and optimization of an inset fed circular microstrip patch antenna using DGS structure for applications in the millimeter wave band." In *2016 International Conference on Wireless Networks and Mobile Communications (WINCOM)*, pp. 99-103. IEEE, 2016. https://doi.org/10.1109/WINCOM.2016.7777198
[30] Dheyab, Ehab, and Nidal Qasem. "Design and optimization of rectangular microstrip patch array antenna using frequency selective surfaces for 60 GHz." *International Journal of Applied Engineering Research* 11, no. 7 (2016): 4679-4687.
[31] Panda, Ribhu Abhusan, Suvendu Narayan Mishra, and Debasis Mishra. "Perturbed elliptical patch antenna design for 50áGHz Application." In *Microelectronics, Electromagnetics and Telecommunications*, pp. 507-518. Springer, New Delhi, 2016. https://doi.org/10.1007/978-81-322-2728-1_47
[32] Emara, Hesham Mahmoud, Hussein Hamed Mahmoud Ghouz, Sherif Khairy El Dyasti, and Mohamed Fathy Abo Sree. "Novel Compact Microstrip Antennas With Two Different bands For 5G Applications." In *2022 International Telecommunications Conference (ITC-Egypt)*, pp. 1-6. IEEE, 2022. https://doi.org/10.1109/ITC-Egypt55520.2022.9855704
[33] Gupta, Neha. "Effects of slots on microstrip patch antenna." *International Research Journal of Engineering and Technology (IRJET)* 4, no. 2 (2017): 1132-1135.
[34] Kumar, Raj, J. P. Shinde, and M. D. Uplane. "Effect of slots in ground plane and patch on microstrip antenna performance." *International journal of recent trends in engineering* 2, no. 6 (2009): 34.
[35] Binshitwan, Anas Abu Bakr, Seraj Mohamed Keskeso, Abdulmunem Adel Alquzayzi, and Ahmed Elbarsha. "38GHz Rectangular Microstrip Antenna with DGS for 5G Applications." In *2021 International Congress of Advanced Technology and Engineering (ICOTEN)*, pp. 1-4. IEEE, 2021.

[36] Paragya, Dhatu, and Hartono Siswono. "3.5 GHz rectangular patch microstrip antenna with defected ground structure for 5G." *ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika* 8, no. 1 (2020): 31. https://doi.org/10.26760/elkomika.v8i1.31
[37] Sodhi, Sukhamrit Pal Singh, and Priya Chabra. "Effect and design of microstrip patch antenna with defected ground structure." *International Journal of Engineering Research & Technology (IJERT,)* 9, no. 02 (2020). https://doi.org/10.17577/IJERTV9IS020200