# Design of Low-Cost, Circularly Polarized, and Wideband U-Slot Microstrip Patch Antenna with Parasitic Elements for WiGig and WPAN Applications

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***Abstract*** **─** In this article, a well matched U-Slot Microstrip Patch Antenna (MPA) with two paratactic elements is designed and simulated. The antenna is designed to resonate at 60 GHz (V-band) and exhibits a wideband extend from 53.3 GHz to 60.8 GHz with more than 87% total efficiency. The presence of U-slot makes a current perturbation in the antenna which contributes to generate a Circular Polarization (CP). The 3-dB Axial Ratio (AR) is extended from 56 – 57.2 GHz (~ 1.2 GHz bandwidth). The analysis and optimization processes throughout this paper are carried out using Finite Element Method (FEM) and verified with Finite Integration Technique (FIT). Good agreement between the results by the two simulators is obtained. Hence, the performance of the proposed antenna makes it a good candidate for fifth generation applications at V-band like Wireless Gigabit Alliance (WiGig) and Wireless Personal Area Network (WPAN).

***Index Terms*** **─** Circular Polarization, MPA, Parasitic elements, U – slot, V-band, WPAN, WiGig.

## I. INTRODUCTION

This paper is an extension of work originally presented in EuCAP 2019 [1]. The unlicensed V-band at 60 GHz has motivated researchers to obtain a high data rate for short range communications within 10 meters [2]. The V-band has applications like WiGig and WPAN. Since the battery life is the main concern; the V-band has used to compensate between bandwidth efficiency and low power consumption [3]. The antennas at millimeter need to exhibit a high gain, wide bandwidth, and small size. MPAs are promising candidate for mm-wave applications, where the antenna is low-profile, can easily integrated with a Monolithic Microwave Integrated Circuit (MMIC), light in weight, and low fabrication cost. The main disadvantage of MPA is the narrow bandwidth [5]. Multilayer antenna structures using Low-Temperature Co-fired Ceramic (LTCC) technology in order to enhance the antenna bandwidth [6-8]. The complex fabrication processes of LTCC technology lead to a high manufacturing cost as well as high antenna volume. Parasitic elements [9], V – slot [10] and U – slot [11-12] also have used to enhance the antenna bandwidth. Due to the advantages of CP antennas over the linearly polarized (LP) antennas [13], CP is more preferable than LP. CP antennas are very prosperous in combating the multi path fading, eliminate the Inter – Symbol Interference (ISI), and they are vigorous to polarization mismatch [13-14]. The strength of the received signal is approximately same nevertheless of the CP antennas directions which make it likable for mm-wave applications.

In this article, the design of a CP matched wideband mm-wave antenna is developed. The simulation of the designed antennas was carried out using the FEM numerical method [15] and verified with the FIT numerical method [16]. The presence of parasitic elements enhances the antenna bandwidth. The U–slot allows current perturbation and the current take longer path. The U–slot dimensions are optimized to obtain a wide bandwidth. The proposed antenna exhibits a CP through the using of the two opposite square corners truncation as well as the U–slot. The truncation corners with U–slot work to generate two orthogonal filed components with equal amplitudes which are a necessary to obtain CP antennas. The proposed antenna is mounted on Netlec NH9338 ( $\varepsilon_r = 3.38$ ) substrate with substrate thickness h = 0.2 mm and loss tangent $\tan\delta = 0.0025$.

In the following sections, the antenna structure and design of the CP wideband antenna is described, and then simulated results are presented and discussed.

## II. ANTENNA STRUCTURE AND DESIGN

At the first, a single square MPA using λ/4 feeding network is designed to resonate at 60 GHz. The antenna mounted on substrate with dielectric constant ( $\varepsilon_r$ ) of 3.38 and height (h) of 0.2 mm supported by conducting

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ground plane. The patch length (L) dimension is calculated from the following equation [5]:

$$L = \frac{c}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \,, \tag{1}$$

where $c$ is the speed of light, and $f_r$ is the resonant frequency of the antenna.

The dimensions of a single element antenna are optimized to resonate at 60 GHz while exhibits a CP. The antenna structure and dimensions is illustrated in Fig. 1. The square patch with length (L) of 1.28 mm, ground plane dimensions are $W_g$ by $L_g$ with the same dimensions as the substrate. The 50Ω feed length $L_f$, and width $W_f$ while the λ/4 section with length $L_{98\Omega}$ and width $W_{98\Omega}$ is used to match the 50Ω feed line with the patch antenna.

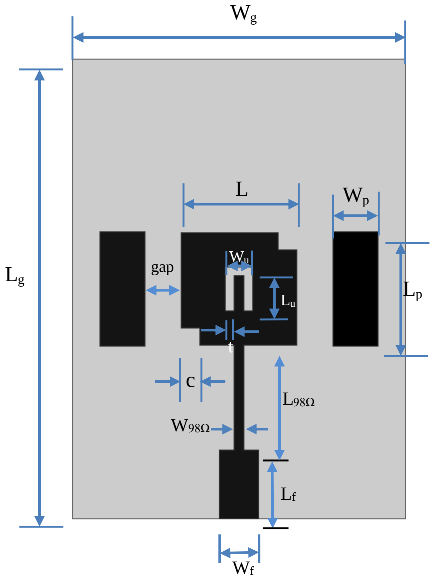



Fig. 1. The proposed corner-truncated square MPA antenna with two parasitic elements using λ/4 feeding network.

## III. SIMULATION RESULTS AND DISCUSSION

A parametric study has been conducted in order to enhance the MPA bandwidth by varying the U – slot dimensions ($L_u$, $W_u$, and $t$) in addition to the parasitic elements dimensions and location ($L_p$, $W_p$, and *gap*). The square truncation area ($c^2$) is optimized in order to get a circularly polarized antenna. The optimized dimensions of the proposed antenna with U – slot, parasitic elements, and truncation area in order to obtain a wide bandwidth with CP are shown in Table 1.

Table 1: Optimized dimensions of the proposed antenna in mm

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $L$ | 1.28 | $c$ | 0.2 |
| $L_g$ | 5.23 | $W_g$ | 3.7 |
| $L_{98\Omega}$ | 1.2 | $W_{98\Omega}$ | 0.1 |
| $L_f$ | 0.775 | $W_f$ | 0.443 |
| $L_u$ | 0.5 | $W_u$ | 0.3 |
| $t$ | 0.1 | $gap$ | 0.4 |
| $L_p$ | 1.3 | $W_p$ | 0.5 |

Fig. 2 illustrates the effect of varying the parasitic elements dimensions ($L_p$, and $W_p$) with *gap* = 0.4 mm and the other parameters are fixed as indicated in Table 1. The effect of varying the U – slot dimensions ($L_u$, and $W_u$) with $t$ = 0.1 mm is shown in Fig. 3.

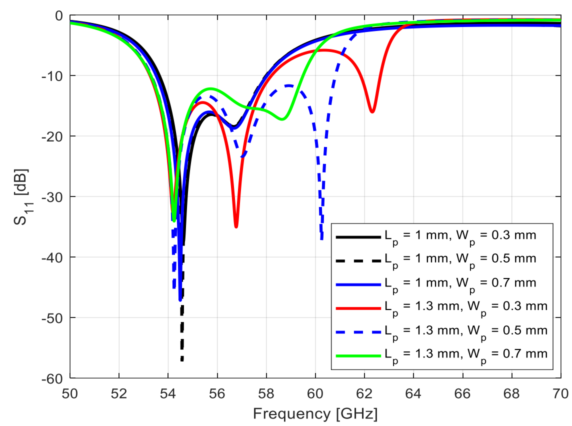



Fig. 2. S11 of the proposed antenna with varying parasitic elements' dimensions ($L_P$ and $W_P$).

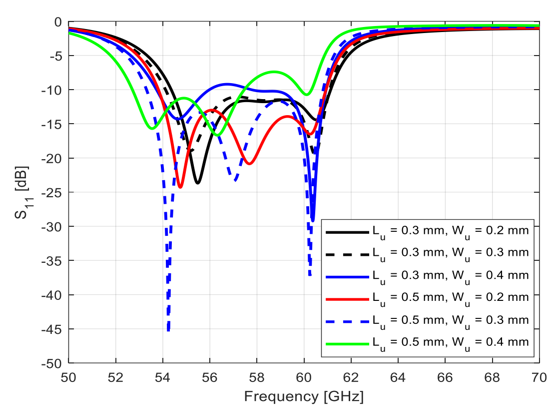



Fig. 3. S11 of the proposed antenna with varying U – slot dimensions ($L_u$ and $W_u$).

Figure 4 illustrates the $S_{11}$ using High Frequency Surface Structure commercial software (based on the FEM method) and CST Microwave Studio (based on FIT method) for the optimized dimensions indicated in Table 1. Small difference between the two simulated results is observed due to the different mesh sizes between the two simulators.

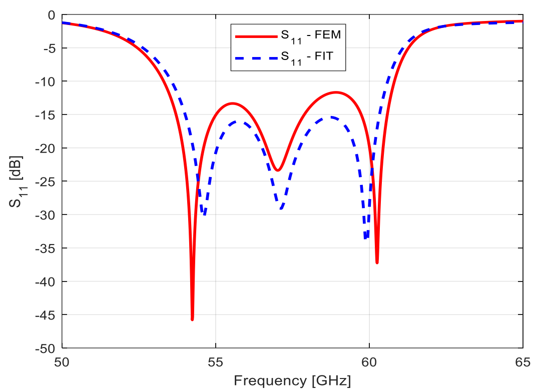



Fig. 4. $S_{11}$ of the proposed antenna using FEM and FIT.

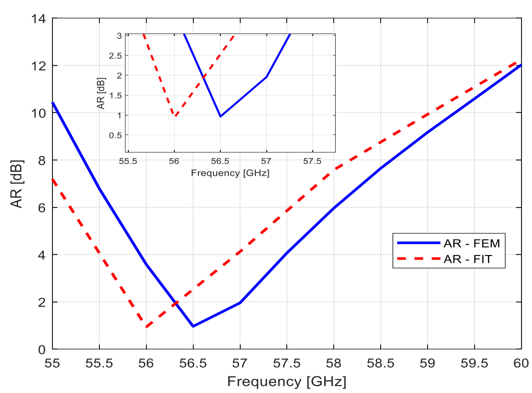



Fig. 5. AR versus the frequency using FEM and FIT.

The simulated bandwidths are 53.32 – 60.82 GHz (7.5 GHz), and 53.5 – 60.6 GHz (7.1 GHz) using FEM and FIT respectively. Figure 5 shows the AR with CP in the frequency bands of 56.1 – 57.2 GHz (1.1 GHz) and 55.64 – 56.74 (1.1 GHz) using FEM and FIT respectively. The radiation patterns in xz and yz planes using FEM and FIT at the resonant frequency (60 GHz) are illustrated in Fig. 6. Good agreement between results is obtained. The maximum realized gain is shown in Fig. 7 on the left y-axis with maximum values of 7.2 dB at 59.5 GHz and 7.63 dB at 58 GHz. Less than 1.3 dB and 0.43 dB gains variation along the antenna bandwidth using FEM and FIT respectively is obtained. The total efficiency using FIT along the entire antenna bandwidth is greater than 78% with maximum value of 92.6% at 57 GHz as illustrated in Fig. 7 on the right y-axis. The radiation efficiency is more than 87% along the antenna bandwidth using FEM and FIT. The surface current distributions of the proposed MPA with the two parasitic elements at 53 GHz, 55 GHz, and 60 GHz are shown in Fig. 8. It can be observed that the two parasitic elements act as two radiators and the presence of U – slot allows the current perturbation. It is clear that the peak current is focused around the patch element as well as the two parasitic elements.

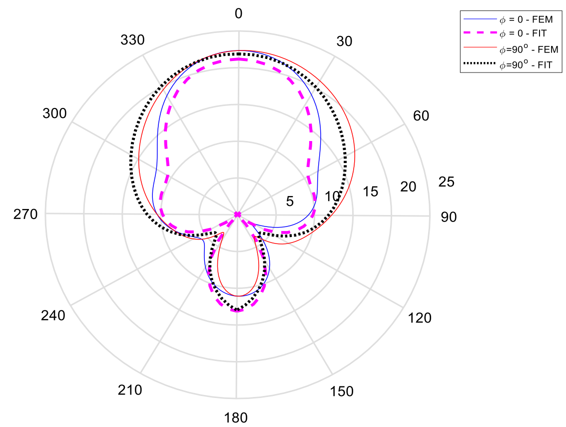



Fig. 6. Total gain of the antenna at xz– and yz–planes.

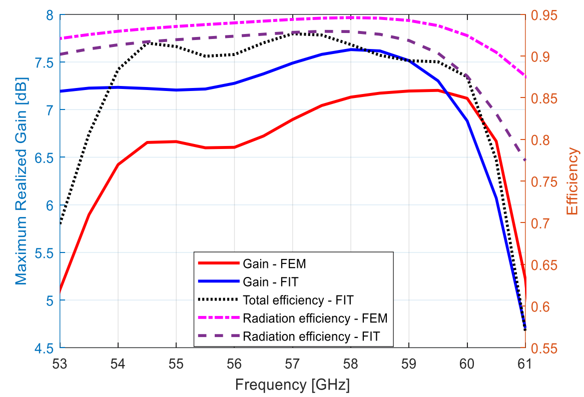
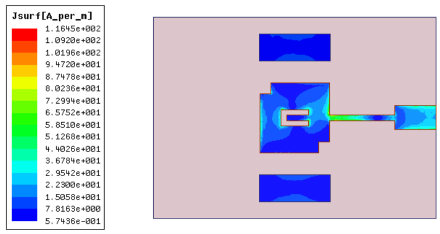


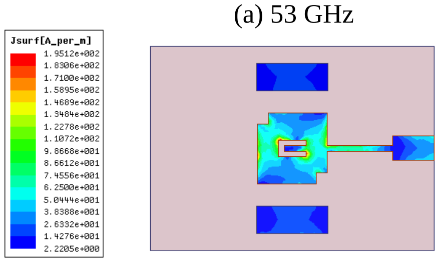

Fig. 7. Maximum realized gain and efficiencies against the frequency using FEM and FIT.

## IV. CONCLUSION

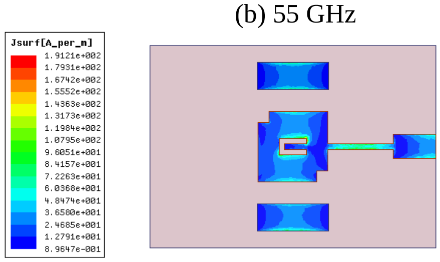
Low–cost CP microstrip antenna with wide bandwidth for the 5G applications like WPAN and WiGig is provided. The proposed antenna with more than 7.1 GHz bandwidth (around 13%) is designed and simulated. The antenna matched by λ/4 matching network. The proposed antenna is mounted on a single layer which yields a low manufacturing cost. The proposed antenna exhibits a circular polarization within 1.1 GHz (around 1.94%) and a maximum gain of 7.2 dBi and 7.63 dBi at 60 GHz using FEM and FIT respectively. The total antenna efficiency is more than 78% along the entire antenna bandwidth. The gain-frequency variation is less than 1.3 dB over the antenna bandwidth which gives a stable antenna performance and makes the antenna as a good candidate for the 5G applications.




(a) 53 GHz




(b) 55 GHz




(c) 60 GHz

Fig. 8. The surface current distributions of the patch antenna with the two parasitic elements at (a) 53 GHz, (b) 55 GHz, and (c) 60 GHz.

## REFERENCES

[1] M. S. Ibrahim, "Low-cost, circularly polarized, and wideband U-slot microstrip patch antenna with parasitic elements for WiGig and WPAN applications," 13th *Euro. Conf. on Ant. and Prop. (EuCAP 2019)*, Krakow, Poland, 31 Mar.-5 Apr. 2019.

[2] J. N. M. T. S. Rappaport and F. Gutierrez, "State of the art in 60-GHz integrated circuits and systems for wireless communications," *Proceedings of the IEEE*, vol. 99, pp. 1390-1436, 2011.

[3] R. Zhou, D. Liu, and H. Xin, "A wideband circularly polarized patch antenna for 60 GHz wireless communications," *Wireless Engineering and Technology*, vol. 3, no. 3, p. 4, 2012.

[4] B. Lee and Y. Yoon, "Low profile, low cost, broadband millimeter-wave antenna array for high data rate WPAN systems," vol. PP, 2017.

[5] C. A. Balanis, *Antenna Theory: Analysis and Design*. 4th ed., John Wiley & Sons, 2016.

[6] K.-S. Chin, E. S. Li, J. Huayan, et al., "60-GHz wideband LTCC microstrip patch antenna array with parasitic surrounding stacked patches," *IET Microwaves, Antennas & Propagation*, p. 8, 2018.

[7] L. Wang, Y. Guo, and W. Sheng, "Wideband high-gain 60-GHz LTCC L-probe patch antenna array with a soft surface," *IEEE Transactions on Antennas and Propagation*, vol. 61, pp. 1802-1809, 2013.

[8] H. Chu, Y. Guo, and Z. Wang, "60-GHz LTCC wideband vertical off-center dipole antenna and arrays," *IEEE Transactions on Antennas and Propagation*, vol. 61, pp. 153-161, 2013.

[9] A. A. Abdelaziz, "Bandwidth enhancement of microstrip antenna," *Progress In Electromagnetics Research, PIER*, vol. 63, pp. 311-317, 2006.

[10] K.-F. Lee, S. S. Yang, A. A. Kishk, and K.-M. Luk, "Design and study of wideband single feed circularly polarized microstrip antennas," *Prog. In Electromag. Res. C*, vol. 80, pp. 45-61, 2008.

[11] S. Wi, Y. Lee, and J. Yook, "Wideband microstrip patch antenna with U-shaped parasitic elements," *IEEE Transactions on Antennas and Propagation*, vol. 55, pp. 1196-1199, 2007.

[12] M. S. Ibrahim, "2 x 2 circularly polarized mimo antenna at ka-band for fifth generation applications," *Inter. Journal on Communications Antenna and Propagation (IRECAP)*, vol. 9, no. 2, 2019.

[13] F. A. Dicandia, S. Genovesi, and A. Monorchio, "Analysis of the performance enhancement of MIMO systems employing circular polarization," *IEEE Transactions on Antennas and Propagation*, vol. 65, pp. 4824-4835, 2017.

[14] J. Wang, Z. Lv, and X. Li, "Analysis of MIMO diversity improvement using circular polarized antenna," *International Journal of Antennas and Propagation*, vol. 2014, p. 9, 2014.

[15] *High Frequency Surface Structure (HFSS) (15 ed.)*. Available: http://www.ansys.com

[16] *CST Microwave Studio 2015*. Available: https://www.cst.com/products/cstmws

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