A New Configuration Of Broadband Patch Antenna With Circular Polarization For Wireless Power Transmission

Ouberri Fatima [1,*], *Tajmouati* Abdelali[1], *Chahboun* Noha[2], *El Abdellaoui* Larbi[1], *Lakhssassi* Ahmed[3]

[1] MIET Laboratory, Hassan First University of Settat, Morocco
[2] LABTIC Laboratory, ENSA of Tanger, University Abdelmalek Essaadi, Morocco.
[3]LIMA – Laboratory of Advanced Microsystems Engineering, University of Quebec in Outaouais Gatineau, Canada

Abstract. An innovative design of a circular polarization antenna for wireless power transmission is described. The suggested antenna is simply constructed, which consists of a square radiating patch having a slotted center with feeding via a probe and an L-shaped ground plane. The application of this L-shaped ground allows a short connection of the probe power supply to the square patch while retaining a certain elevation from the ground plane to the square patch while using an air layer substrate, thereby allows a proper adaptation of the impedance and an improvement of the bandwidth. The purpose of utilizing the slot in the center of the square patch is to create a circular polarization with an axial ratio value of under 3dB. By means of a through-hole through the vertical L-shaped ground plane, the patch radiating can be readily excited with a probe feed pointing into the same plane as the patch. This approach allows to further improve the bandwidth of the circular polarization. In this way, the CP bandwidth of the proposed antenna is significantly extended by about 10% and a good impedance matching over a wide bandwidth is obtained. The features of the proposed design are investigated and optimized using a 3D electromagnetic (EM) solver. It was found that the proposed antenna covers a broad band of 425MHz, has a 3 dB axial ratio CP bandwidth of approx. 85% of the resonant band, and a gain level of 7.4 dBi or more in the bandwidth of the resonant band. Besides the low cost of the proposed antenna arising from its simplest structure, the resulting performance leads the antenna to be a strong candidate among circularly polarized, single element, and single feed patch antennas.

Keywords. Wireless Power Transmission, Wide-Band, Circular polarization, Patch antenna, L-shaped.

1 Introduction

Circularly polarized (CP) antennas have been drawing a significant amount of attention in wireless communication technologies owing to their intrinsic advantages over linearly polarized antennas. These include higher sensitivity in the orientation angle from transmitter to receiver, immunity to multipath reflection, and elimination of polarization failures, resistance against Faraday rotation effects from the ionosphere, and the easiness of integration. There are numerous kinds of antennas available to accomplish CP radiation. A microstrip patch antenna is considered as a classical type of CP antenna. This form of antenna has been regarded as the best solution in compact communication devices because of its prominent characteristics. Microstrip patch antennas have several advantages over conventional antennas, including lightweight, low profile, easy and inexpensive construction, and flexibility in configuration[3][4].

Generally, the CP waves are capable of being excited using two orthogonal patch modes of equal amplitude but in phase quadrature with the sign which indicates the direction of rotation. For this requirement can be provided, there are two different methods available: dual-fed type and single-fed type[5]. The first approach consists of double feeds with an external polarizer. However, this requires more space for the feeds on the dielectric and increases the losses of the antenna, rendering the design and fabrication very complicated. Whereas the other approach is made up of a singular patch antenna having an appropriate excitation or a patch array with an adequate arranging and phasing[6]. Several forms of the microstrip antennas which are able to perform in circular polarization have been documented in the literature, such as square, circular, pentagonal, equilateral, ring, and elliptical antennas. The single-feed patch antennas are being considered as a strong candidate to meet the above requirements. However, they exhibit inherent restrictions in terms of gain, impedance, and axial ratio bandwidth. These limitations

* Corresponding author: f.ouberri@uhp.ac.ma

are commonly due to the high-quality factor of the natural resonance of the patch antenna[7].

The development of planar antennas with multiband or wideband operating capabilities as well as small size, very low profile and seamless integration into radio systems became an interesting and realistic research challenge in recent years. [8][9][10] service to sustain wireless communication, particularly for multimedia communication applications (data, voice, image and video) and wireless radio technologies (Bluetooth, Wi-Fi, GPRS, UMTS, WiMAX). They are highly successful. In addition, the applications demand high bandwidth among the mobile communication devices [11]. Several techniques have been developed to satisfy the requirement for enhanced bandwidth and peak gain of microstrip antennas, one commonly used method is to use a layer of air or a foam substrate between the ground plane and the radiating element in which the observed CP bandwidths are about 3.5% [12]. To attain significantly larger CP bandwidths (>10%) for patch antennas, multi-layer layered antenna types with CP bandwidth have been examined. While such layered patches (up to three layers) may have advantages including high bandwidth and shallow profile (antenna width), their packaged patch structure may result in increased manufacturing cost. Therefore, to get a straightforward structure (single layer), easy feeding mechanism as well as low fabrication cost, employing an L-shaped ground plane has been recently discussed in [13]. Nevertheless, both of the above developments using an L-shaped ground plane continue to necessitate a planar size.

In this paper, we prove that a single-element patch antenna is capable of achieving a CP bandwidth of more than 10% by employing a new and simple feed structure (see Fig. 1). The proposed feed structure includes a probe feed aligned in a same plane as the radiating patch of the antenna, which is unlike the conventional probe feed located between the radiating patch of the antenna and the ground plane. By assuming the proposed feeding structure, a square patch antenna with a slot in the middle and a heavy air substrate can be steered. Nevertheless, such a substrate of thick air can be driven with smooth impedance matching throughout a broad frequency range, as well as good CP radiation features can be obtained. The achieved broadband impedance bandwidth is chiefly attributable so far to the effect of the proposed design supports the use of a short probe pin, although the antenna has a thick air-layer substrate, making the probe inductance introduced low or negligible, and therefore its impact on the impedance matching of the antenna can be disregarded. The design details of the proposed CP are presented.

2 Antenna Design

A Broadband circularly polarized patch antenna is conceived in this article, the wideband circularly polarized microstrip antenna configuration with its suggested feeding structure for integrating with more than one wireless communication system has been presented in Fig. 1. Of particular significance is the radiating element, which forms the upper portion of the antenna, constructed of copper metal, has a square shape of the side length of L_p, with a slot in the middle which is sliced to serve as a disturbance so to produce two orthogonal nearly deviated resonance methods for the CP beam. the details of the design of the radiating element is presented in[1]. The radiating element is positioned above an L-shaped ground plane, which is composed of two masses, one horizontally with an area of $L_g \times W_g$ and the second one vertically with $S \times L_g$. The aim of the addition of the supplementary vertical mass in the proposed design is to supply the patch antenna with a probe feed that is aligned on the identical plane as the radiating patch. To separate the patch and the ground plane, a foam substrate with approximately the same relative permittivity as air and a thickness of h are used.

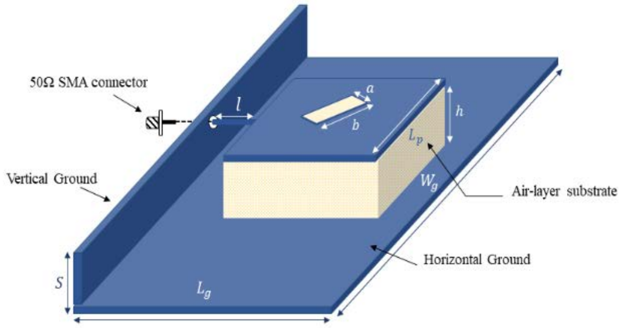

Fig. 1. The configuration of the proposed antenna.

In the proposed design, we focused on two aspects, eliminating the problem of the effect of a high inductance of the probe on the adaptation of the antenna impedance and the support of the coaxial connector. To reach the first goal, the length of the probe pin (l) can be maintained at a small amount. Furthermore, to achieve the second one, it is necessary to notice that the breadth of the vertical ground can hardly be just wide enough. To ensure effective CP radiation over a wide band, a parametric study has been made as a function of the length L_p of the square patch and the vertical ground width, Fig. 2. (a), (b) and (c) illustrate the evolution in terms of the reflection coefficient, the axial ratio and the gain respectively. Whereas Fig. 3. (a) and (b) plot the evolution with regard to the reflection coefficient and the axial ratio respectively.

The choice of the air layer substrate thickness h is heavily depending on the required operating bandwidth. A wider bandwidth will necessitate a larger substrate thickness. Therefore, in this case, the air layer substrate thickness should be specified to be around 15% of the free bandwidth. Concerning Horizontal ground plan outline dimensions, comparatively insignificant influences upon the radiating frequency of the antenna, but mostly they influence on the directivity of the antenna radiation patterns. A wider ground plane can reduce the back radiation of the antenna., thereby improving the directivity of the antenna (i.e., the gain of the antenna be highest with a bigger ground plane).

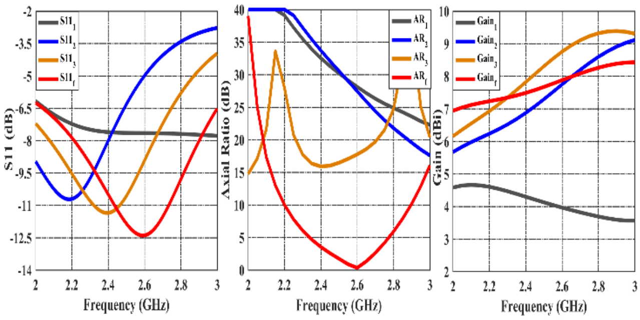

Fig. 1. Simulated curves for varying the length L_p of the square patch of (a). the reflection coefficient, (b). the axial ratio, (c). the gain.

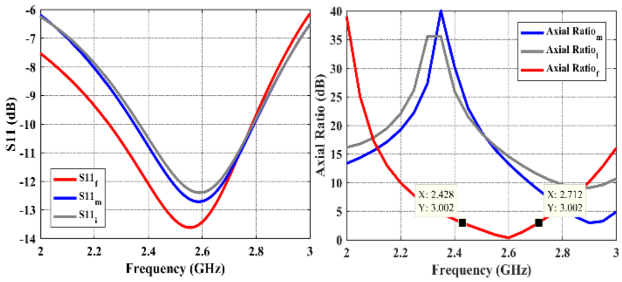

Fig. 2. Simulated curves for varying the vertical ground width of (a). the reflection coefficient, (b). the axial ratio.

From the mentioned figures we can notice that the variation of the length of the patch and the width of the vertical ground can considerably impact the performance of the antenna, which involves several modifications and optimizations. After a series of optimizations, it was found that for getting a high quality of CP coverage across a broad range of bandwidths, the vertical ground width must be greater than twice the length of the square radiating patch side. And for the building facility, the vertical ground has been chosen to be identical with the horizontal ground in width, which makes its construction easier. The final dimensions of the proposed antenna are shown in Table 1.

Table 1. Dimensions of the proposed antenna.

Parameter	L_p	L_g	W_g	S
Value(mm)	*43*	*100*	*200*	*23*
Parameter	***a***	***b***	***h***	***l***
Value(mm)	*5.65*	*12.6*	*18*	*3.8*

3 Results and Discussions

After numerous steps of optimization and validation of the proposed antenna using a 3D electromagnetic simulator, the performances of the broadband circularly polarized patch antenna, including return loss, gain, radiation pattern and axial ratio are being evaluated. The simulated reflection coefficient obtained by the solver is given in Fig. 4. Through this figure, the wideband nature is clearly observed up to 530MHz and it is clear from it that the proposed antenna is able to supply good input matching impedance with a return loss of -12.81dB and -13.43dB for the two center frequencies of the ISM and WIMAX respectively.

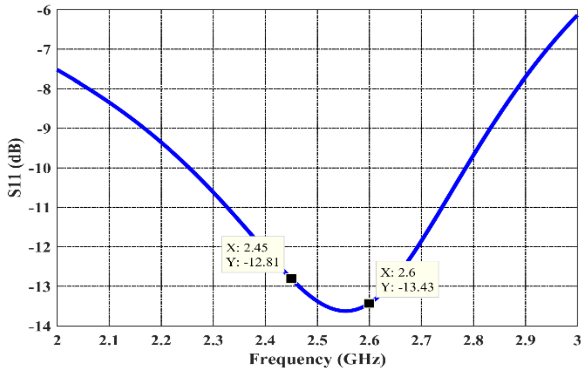

Fig. 3. Simulated S-parameter of the proposed antenna.

To accomplish circularly polarized behavior, the axial ratio of the antenna must be less than 3dB. Fig. 5. presents the axial ratio of the proposed structure. As pictured from the figure, the designed antenna has the capability of generating a circular polarization (CP) with an axial ratio bandwidth of 3 dB up to 332 MHz. One of the most important characteristics of the antenna is the peak gain, which is the average gain of the antenna and depends on the efficiency. The peak gain of the proposed antenna for the operating frequencies within the obtained bandwidth is plotted in Fig. 6. One can easily perceive that the peak antenna gain amounts to about 8.2 dBi, and the overall average gain amount is around 7.4 dBi or more.

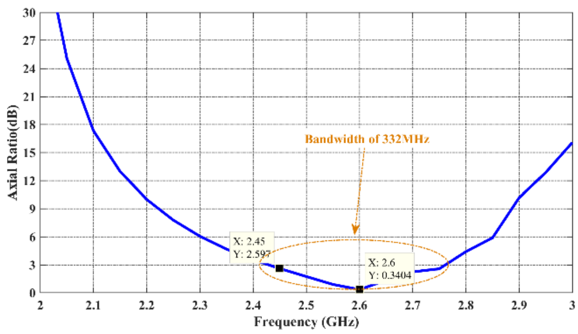

Fig. 4. Simulated Axial Ratio of the proposed antenna.

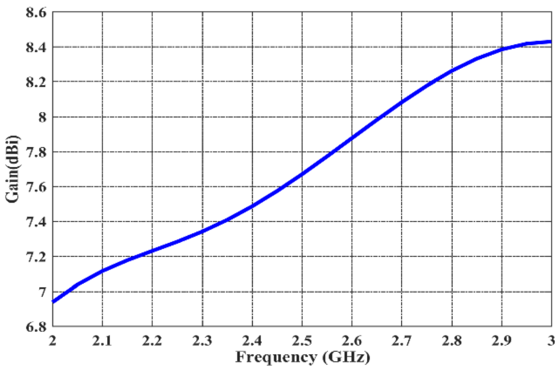

Fig. 5. Simulated result peak gain of the proposed antenna.

The radiation pattern is consequently taken into account to predict the capabilities of the extended network in harvesting microwave energy. Fig. 7. is a simulation of the radiation pattern for the CP antenna developed in the E(Phi=90°) and H(Phi=0°) planes for the two center frequencies of the ISM and WIMAX respectively. As is apparent from the figures, this antenna exhibits a very strong directional radiation characteristic across all frequencies.

To more accurately evaluate the efficiency of the offered antenna, a performance-based comparison of the proposed CP antenna with some other published antenna designs is presented in Table 2. By studying this table, it is revealed out that the proposed CP antenna has nearly the greatest gain with the smallest size. within these antennas. Moreover, the designed antenna supplies good impedance bandwidth and axial ratio bandwidth with high CP quality.

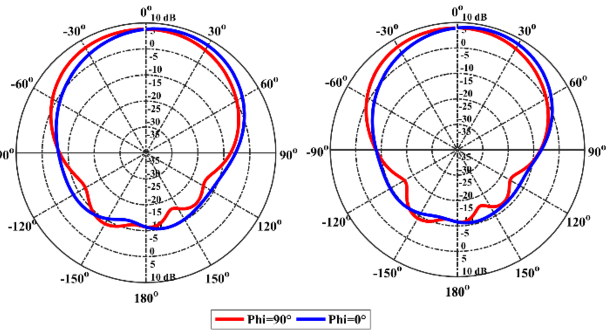

Fig. 6. The radiation pattern of the proposed antenna: (a) 2.45GHz, (b) 2.6 GHz.

Table 1. A comparison of the capabilities of the proposed antenna with other existing antennas.

Antenna	*AR Bdw (MHz)*	*Peak Gain (dBi)*	*Size (mm³)*	*Design Technique*
[13]	129	7.66	190× 170× 45	Monolayer circular patch, L-shaped ground, with parasitic.
[14]	150	8.6	250× 250× 60	Square patch with 3 slots, One layer with an L-shaped ground.
[15]	81	8.15	200× 200× 38	Monolayer circular patch, L-shaped ground, with parasitic.
Proposed	332	8.2	200× 100× 18	square patch with a slot in the center, Single layer L-shaped ground.

Conclusion

An innovative single-element probe-fed patch antenna for broadband CP radiation has been successfully designed in this paper. The purpose of this study is to cover the needs in applications involving wireless power transmission. The proposed concept is extremely basic in its structure and may be conveniently designed with very poor cost, making it easy to combine with microwave integrated circuits and rendering it highly adaptable for wireless communication applications. The proposed antenna offers various advantages at one time, including successful input impedance matching with significantly broader operating bandwidth, achieving a wide axial ratio bandwidth. Additionally, excellent antenna gain and wide radiation patterns have also been achieved.

References

1. F. Ouberri, A. Tajmouati, J. Zbitou, A. Errkik, L. El Abdellaoui, and M. Latrach, "A Novel Circular Polarized Antenna Array for Wireless Power Transmission," 2th Int. Conf. Embed. Syst. Artif. Intell., 2021.
2. C. Li, X. Zhu, P. Liu, S. Member, and C. Yu, "A Metasurface-Based Multilayer Wideband Circularly Polarized Patch Antenna Array With a Parallel Feeding Network for Q-Band," IEEE Antennas Wirel. Propag. Lett., vol. **18**, no. 6, pp. 1208–1212, 2019, DOI: 10.1109/LAWP.2019.2912624.
3. J. Chen, C. Jin, S. Member, B. Zhang, and Z. Shen, "Combined Triangle Quarter-Wavelength Patches and Their Application to High-Gain CP Antenna," IEEE Antennas Wirel. Propag. Lett., vol. PP, no. c, p. 1, 2019, DOI: 10.1109/LAWP.2019.2954583.
4. F. Ouberri, A. Tajmouati, J. Zbitou, I. Zahraoui, and M. Latrach, "A Novel Design of Circularly Polarized Pentagonal Planar Antenna for ISM Band Applications," TELKOMNIKA Telecommun. Comput. Electron. Control, vol. **18**, no. 1, pp. 1–8, 2020, doi: 10.12928/TELKOMNIKA.v18i1.xxxxx.
5. G. K. Reddy, G. U. Bhargava, and P. Sridhar, "Fabrication of patch antenna with circular polarization for wireless LAN applications," Int. Conf. Electr. Electron. Commun. Comput. Technol. Optim. Tech. ICEECCOT 2017, vol. 2018-Janua, pp. 98–102, 2018, DOI: 10.1109/ICEECCOT.2017.8284647.
6. S. S. Gao, Q. Luo, and F. Zhu, *CIRCULARLY POLARIZED ANTENNAS*, 2014 John. 2014.
7. F. Ouberri, A. Tajmouati, I. Zahraoui, A. Lakhssassi, M. Latrach, and R. Er-Rebyiy, "A Novel Wideband CPW-Fed Square Aperture Monopole Antenna with Inverted-L Grounded Strips for Wireless and Satellite Applications," 2020 IEEE 2nd Int. Conf. Electron. Control. Optim. Comput. Sci. ICECOCS 2020, 2020, DOI: 10.1109/ICECOCS50124.2020.9314499.
8. M. Gupta and R. Kumar, "Wideband Multi-Polarized Microstrip Patch Antenna for Wireless Communication," Int. J. Comput. Appl., vol. **173**, no. 6, pp. 32–35, 2017, DOI: 10.5120/ijca2017915338.
9. A. K. Singh, A. Sharma, M. Lakshmanan, and D. Gangwar, "A compact circularly polarized multiband microstrip patch antenna with defective ground structure," Int. J. Electron. Telecommun., vol. **65**, no. 2, pp. 195–201, 2019, DOI: 10.24425/ijet.2019.126301.
10. W. Su, J. Li, and R. H. Liu, "A compact double-layer wideband circularly polarized microstrip antenna with parasitic elements," Int. J. RF Microw. Comput. Eng., vol. **31**, no. 1, pp. 1–8, 2021, DOI: 10.1002/mmce.22471.

11. R. Dakir, J. Zbitou, A. Mouhsen, A. Tribak, A. M. Sanchez, and M. Latrach, "A Low-Cost Broadband Planar Antenna," Int. J. Innov. Res. Comput. Commun. Eng., vol. **2**, no. October 2017, pp. 2–5, 2013, DOI: 10.7763/IJCCE.2013.V2.217.
12. N. Rosli et al., “Analysis Performance Of Singly-Fed Circularly Polarized Microstrip Antenna For Wireless Communication,” J. Teknol. (Sciences Eng., vol**. 1**, no. 78: 5–9 (2016) 111–117, pp. 1–6, 2016.
13. C. Y. D. Sim, Y. W. Hsu, C. W. Lin, and G. Yang, "Broadband circularly polarized antenna with moon-shaped parasitic element," Int. J. RF Microw. Comput. Eng., vol. 26, no. **5**, pp. 387–395, 2016, DOI: 10.1002/mmce.20972.
14. C. Y. D. Sim, Y. W. Hsu, and G. Yang, "Slits loaded circularly polarized universal UHF RFID reader antenna," IEEE Antennas Wirel. Propag. Lett., vol. **14**, no. c, pp. 827–830, 2015, DOI: 10.1109/LAWP.2014.2382557.
15. C. Y. D. Sim, C. C. Chen, R. Cao, and B. S. Chen, "A circular patch antenna with a parasitic element for UHF RFID applications," Int. J. RF Microw. Comput. Eng., vol. **25**, no. 8, pp. 681–687, 2015, DOI: 10.1002/mmce.20905.