Dual-Circularly Polarized Patch Antenna using Simple Isolation Techniques and its Array Application

Citation for published version:
Le Bihan, P, Zhaksylyk, Y, Hilario Re, P, Podilchak, S, Garcia-Vigueras, M & Goussetis, G 2018, Dual-Circularly Polarized Patch Antenna using Simple Isolation Techniques and its Array Application. in *12th European Conference on Antennas and Propagation (EuCAP 2018).* Institution of Engineering and Technology, 12th European Conference on Antennas and Propagation 2018, London, United Kingdom, 9/04/18. https://doi.org/10.1049/cp.2018.1135

Digital Object Identifier (DOI):
10.1049/cp.2018.1135

Link:
Link to publication record in Heriot-Watt Research Portal

Document Version:
Peer reviewed version

Published In:
12th European Conference on Antennas and Propagation (EuCAP 2018)

Dual-Circularly Polarized Patch Antenna using Simple Isolation Techniques and its Array Application

Paul Le Bihan[1], Yelzhas Zhaksylyk[2], Pascual David Hilario Re[3],
Symon K. Podilchak[3], María García-Vigueras[1], George Goussetis[3]
[1] Institut d'Électronique et de Télécommunications de Rennes, Rennes, France, paul.le-bihan@insa-rennes.fr
[2] Department of Microsystems, University College of Southeast Norway, Vestfold, Norway, yelzhas.zhaksylyk@usn.no
[3] Institute of Sensors, Signals & Systems, Heriot-Watt University, Edinburgh, United Kingdom, s.podilchak@hw.ac.uk

***Abstract* — This paper presents low cost, low complexity, dual-circularly polarized patch antenna designs. The aperture coupled antennas employ simple square slotline loop elements to provide surface current cancellation in the critical regions of the antenna structure. High isolation (below 50 dB) is then obtained between the two antenna inputs, one for each polarization state. Circular polarization (CP) is produced thanks to the use of a planar hybrid coupler, feeding the antenna with two quadrature signals. Reciprocity of these components allows for the use of one port as the input (Tx) and the other one as an output (Rx), making the antenna work in full duplex mode. Also, both right-hand and left-hand circular polarizations are possible by interchanging the Tx and Rx ports, bringing a valuable degree of versatility. The proposed antenna design is also grouped in a 2x2 array for operation at C band (2.45 GHz), and its corresponding results are reported. Possible applications for the single-element and the low profile array include modern short range wireless communications, polarization diversity, direction finding, radar, and other beam steering array applications.**

***Index Terms*—aperture coupled, circular polarization, patch antenna, full duplex, isolation.**

I. Introduction

Nowadays demands for medical sensors, motion capture, power harvesting and collision avoidance, are a source of intensive research in the wireless communications field [1-4]. Moreover, with the major increase of connected devices predicted by the upcoming Internet of Things (IoT), or next generation mobile standards using massive multiple input multiple output (MIMO) systems, the search for compact and low cost antennas can result in significant advantages.

Full duplex operation and single frequency channel utilization are often required in such modern applications. Leakage between Tx and Rx signals, commonly named as self-interference (SI), represents a real obstacle for full duplex high sensitivity systems. Several techniques have been investigated to solve this problem, based on digital processing, for example [5]. Among these full duplex systems, one approach relies on polarization diversity, which can be used to transmit and receive data with a single antenna element, reducing the overall dimensions for the transceiver and the number of antennas required. In order to maintain a high level of isolation between both Tx and Rx ports, circulators are often used, but at the cost of sacrificing antenna compactness and escalating design complexity. Alternatives employing microstrip structures can be found in the literature, such as in [6-8], which maintain a good level of measured isolation between the Tx and Rx ports. Values approaching about 40 dB have been reported.

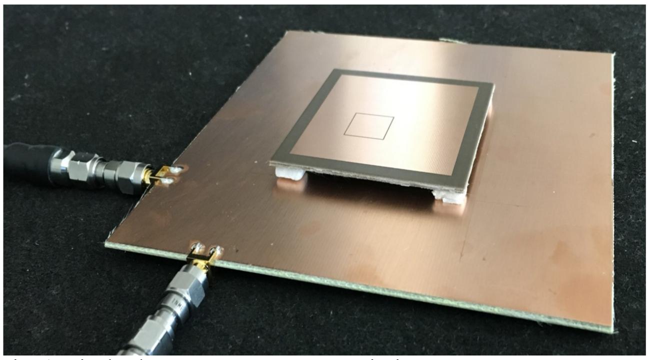


Fig. 1. Single-element antenna prototype in its S-parameter measurement configuration.

Following these developments, this paper proposes a two-port, aperture coupled dual-circularly polarized (DCP) patch antenna design working at 2.45 GHz with an integrated and planar hybrid coupler. Two square loop elements are employed within the patch and the ground plane layers to achieve a higher level of isolation between the feed ports. In particular, values greater than 50 dB are achieved for the single-element. A 2x2 array is also developed where similar performance metrics are observed. The proposed antenna architecture presents a novel way to achieve high isolation while maintaining good antenna performance in terms of matching, gain and CP purity. To the authors' knowledge, no other DCP patch antenna element and array, with such slot inclusions, has been designed previously nor experimentally verified, offering such polarization agility and isolation between its feed ports.

II. Single-Element Antenna Design and Operating Principle

As shown in Figs. 1 and 2, the proposed two-port DCP antenna is made out of two PCB layers. The feeding structure is located on the lower one, which is an FR4 substrate (Ɛr = 4.3; thickness = 1.6 mm) for low cost fabrication. In order to improve its impedance bandwidth, the upper layer is made out of a low ε_r Taconic material (ε_r = 2.17; thickness = 1.52 mm), which supports a square radiating patch.

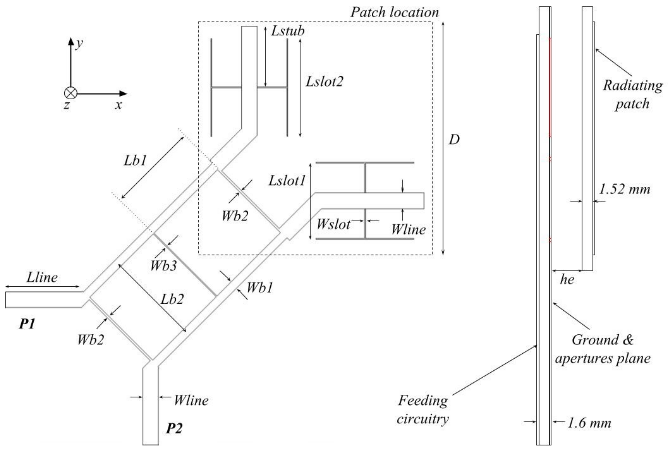


Fig. 2. Antenna architecture and feed system based on a double-box hybrid coupler. Left: bottom view; Right: side view.

A. Feeding Structure

The feeding structure is shown in Fig. 2 and consists of a double-box hybrid coupler [9], with two input ports (P1 and P2). The two outputs of this coupler contain half of the power inserted at P1 and P2 in quadrature. Both these outputs excite the top square patch through two H-shaped slots placed on the ground plane of the coupler.

This way, when P1 is excited, right-hand circular polarization (RHCP) is produced by the antenna, while left-hand circular polarization (LHCP) signals can be received through P2. Dual polarization behavior can be obtained by interchanging P1 and P2. The use of a double-box coupler instead of a classical 90˚ hybrid coupler ensures better matching, improved Tx/Rx isolation and amplitude balance as well as maintained orthogonality of the quadrature signals over a larger bandwidth. This can lead to a lower axial ratio (AR) for the antenna. Additionally, matching is improved by using λ/4 stubs when transferring power from the outputs of the hybrid coupler to the H-shaped slots [10].

B. Port Isolation

Emphasis has been put on achieving high isolation between the ports when designing this antenna. Isolation is strongly impacted by the feeding method and the geometrical configuration of the antenna. The two H-shaped slot lines, transferring power from the output of the hybrid coupler to the patch, must not overlap the perimeter of the patch. This guarantees that a high amount of coupling from the hybrid coupler to the patch is achieved for radiation. Considering the patch dimensions, the two slots are placed very close to each other to respect this constraint. Yet, with such slot elements, one may expect that a significant amount of surface currents circulate around and between the H-shaped slotlines, particularly around their short-circuit terminations [11]. In this critical region, surface currents can then circulate from one H-shaped slot to another, disturbing port-to-port isolation and reducing antenna AR.

Some preliminary investigations on slotline port isolation techniques have been reported in [12] for linearly polarized microstrip loop antennas. Following a similar approach of current cancellation, leads to our proposed technique whose implementation is shown Fig. 3 for the aperture coupled patch. In particular, a new square slot loop is placed on the top radiating patch for improved isolation between its feed ports. This top slot loop is excited by the two H-shaped slots on the lower layer. From each feeding point (located at the mid-point of the loop), current flows through the 2 paths composed by the loop, and then recombines at the other feeding point with a phase difference which directly cancels the current circulation from one H-shaped aperture to the other one. This can realize a strong port-to-port isolation and maintained CP performance for the single-element patch.

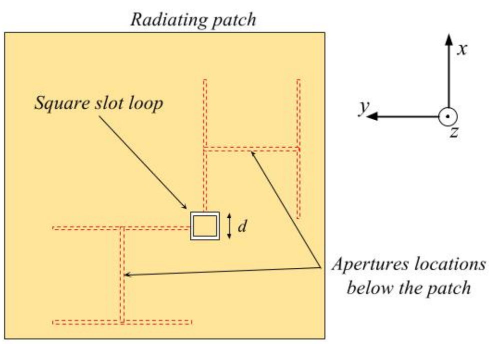


Fig. 3. Square loop placement on top of the radiating patch for enhanced isolation between the RHCP and LHCP antenna ports.

TABLE I
ANTENNA PROTOTYPE DIMENSIONS (MILLIMETERS)

D	he	Lb1	Lb2	Lline
45.35	3	17.73	18.94	14.88
Lslot1	Lslot2	Lstub	Wb1	Wb2
14.79	20	16.9	1.6	0.37
Wb3	Wline	Wslot		
0.2	3.06	0.2		

III. SINGLE-ELEMENT RESULTS

The antenna has been designed and simulated using CST Microwave Studio, then fabricated for experimental verification. The lower substrate layer is made using an FR4 square plate. The upper Taconic substrate is maintained 3 mm above the bottom layer using foam spacers. The antenna has been designed with a 15x15 mm² square slotline loop as described in Sec. II and dimensions are indicated in Table I.

In Fig. 4. it can be observed that this antenna reaches a 6 dBic realized gain at broadside and a 60° half power beamwidth, at 2.32 GHz. According to the simulation, we estimate that this corresponds to a 70% radiation efficiency.

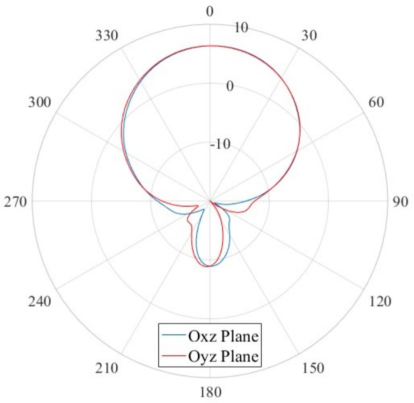


Fig. 4. Measured realized gain pattern (dB) at 2.32GHz. RHCP transmission, Port 1 excited.

Measured and simulated S-parameters are shown in Fig. 5. A narrowband, strong isolation is achieved, reaching 23.7 dB at 2.32 GHz while broadband matching is also demonstrated. Simulation and measurements are only shown for Port P1 in Tx mode and Port P2 in Rx mode. Due to the symmetry of the structure, similar results are observed for the dual configuration.

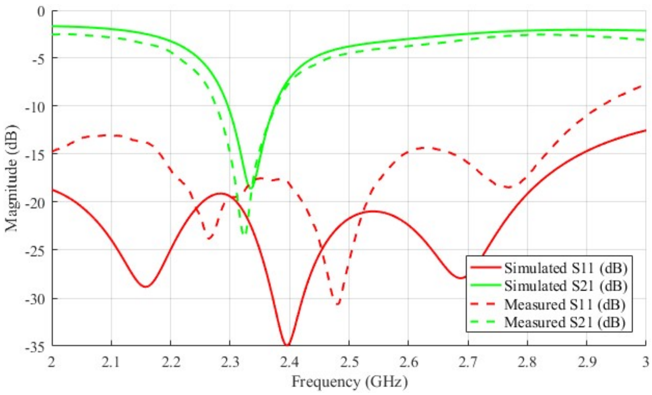


Fig. 5. Antenna S-parameters (dB).

The minor discrepancies between the simulations and measurements in Fig. 5. may be due to several factors. Simulations did not take in account the insertion losses due to the SMA connectors, which may change the port matching, neither the presence of the foam spacers supporting the radiating patch. From our investigations it is also possible that a misplacement of the radiating patch above its feeding apertures, occurring during the fabrication and assembly, can also lead to some performance degradation. Figure 6 shows the antenna AR measured and simulated in the main planes. Regardless of the previous facts, Fig. 6. shows that CP purity is ensured when the antenna main beam points at broadside (where AR < 2 dB). As can also be seen in Fig. 6, there is a lack of symmetry of AR versus theta angle. This can be explained by the asymmetric architecture of the antenna structure (particularly, the feeding slots under the radiating patch).

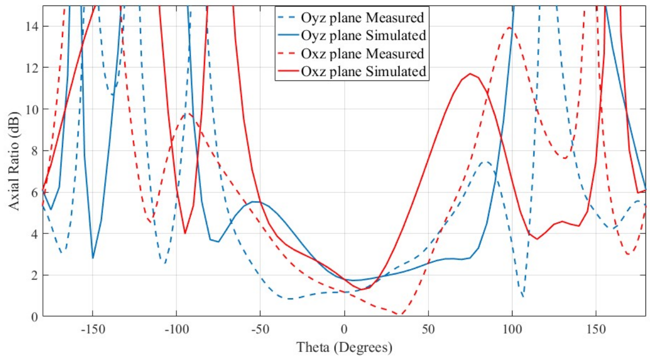


Fig. 6. Axial ratio (dB) at the isolation frequency versus theta (degree) for both *Oxz* and *Oyz* planes. Measured versus simulated results.

IV. Enhanced Isolation & 2x2 Array

As outlined in the previous section, the employed slot helps to assure a good isolation between the antenna input ports. Yet, it has been found that further reduction of this isolation is possible by inserting a second square slot loop on the antenna ground plane, as depicted in Fig. 7. In the following subsections, this second technique is explained together with the study of the DCP antenna in a 2x2 array configuration.

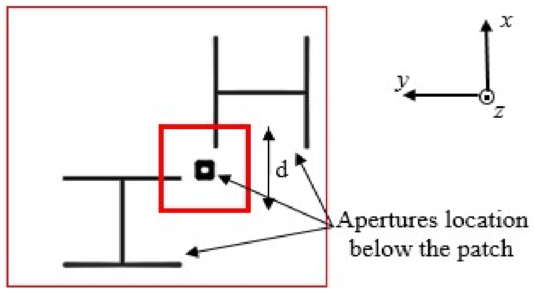


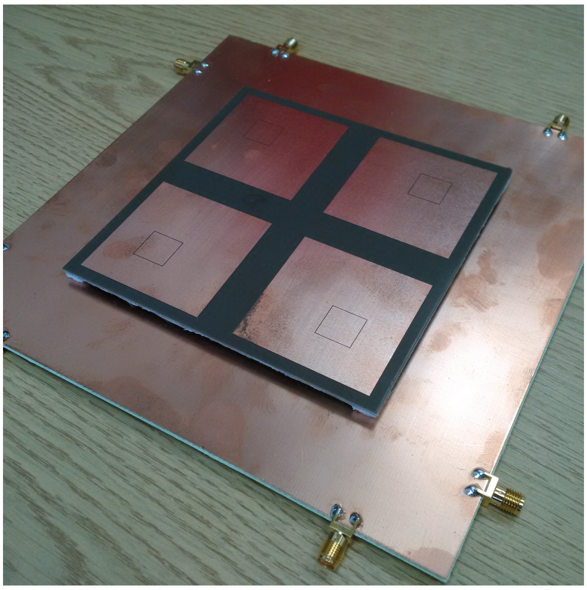
Fig. 7. Isolation improvement approach based on two square slotline loops. Red: on top patch; Black: ground plane loop.

A. *Enhanced Single-Element Antenna Design*

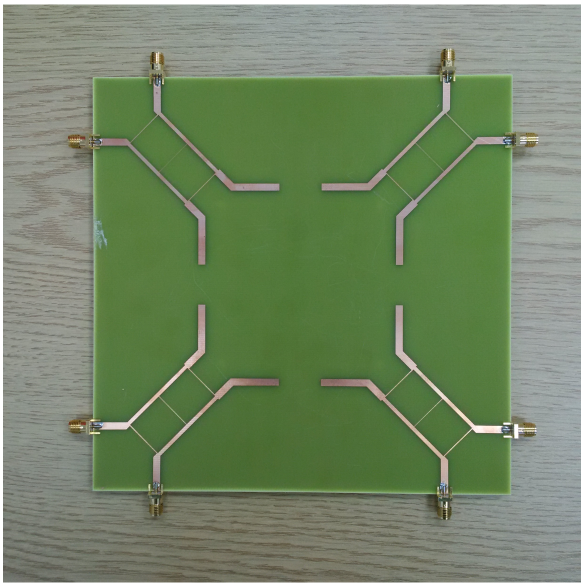
By adopting the strategy shown in Fig. 7, it has been observed from CST full-wave simulations that the antenna isolation reaches 51 dB at 2.4 GHz. Though we could firstly expect this modification of the ground plane to deteriorate the feeding system operation, matching has been maintained under -15 dB from 2.4 to 2.5 GHz and thus, the loop does not seem to cause major issues. For example, the obtained AR remains below 2 dB from a -50 to 50 degree scan angle, while the far-field gain reaches 8.3 dBic at broadside. These promising results have encouraged the manufacturing of an antenna prototype. Measurements have shown that $|S_{11}|$ remains below -20 dB from 2.2 GHz to 2.6 GHz. Yet, the maximum isolation value, reaching 50 dB, appeared to be frequency shifted at 2.35 GHz for the measured structure. This difference could be explained by fabrication and assembly tolerances as mentioned previously. Also, a monostatic co-polarisation measurement has been completed to obtain the far-field gain. At 2.35 GHz, the realized gain is 7.9 dBic, and slightly lowers to 7.5 dBic at 2.4 GHz.

B. 2x2 Array Prototype

We also investigate an array implementation of the proposed full duplex DCP patch antenna. A 2x2 element array was designed employing the double-loop isolation technique explained in the previous subsection. This structure has also been manufactured, as shown Fig. 8.



(a)



(b)

Fig. 8. Fabricated 2x2 array prototype. (a) Top radiating elements; (b) Bottom feed system.

Port measurements have shown that the array elements maintain good matching ($|S_{11}| < -15$ dB) over a 30% bandwidth, centered at 2.33 GHz. Also, isolation properties of the array are very similar to the single-element; i.e. measured isolation values are between 35.7 dB and 50 dB at 2.37 GHz for the dual-polarization feed ports for each of the elements within the array. Regarding the radiation properties, it has been observed from full-wave simulations that the AR was lowered to 0.46 dB when compared to the single-element. This result can be explained by the symmetry in both the *x* and *y*-axis for the 2x2 array. Realized gain is also naturally increased, reaching 10.2 dBic at broadside.

V. CONCLUSIONS

Novel techniques for port-to-port isolation enhancement of an aperture coupled dual-circularly polarized patch antenna has been presented. By strategic placement of a square slotline loop on the radiating patch, a measured isolation of 23 dB was observed. A further study has shown that a combination of two square slotline loops, on both the patch and the ground plane, allows for an isolation of 50 dB, wideband matching (|S11| < -15 dB), and a realized gain of over 7.5 dBic at broadside for a fabricated prototype. The implementation of this antenna into a 2x2 array has also been examined and some initial measurements for our array have been reported. Based on full-wave simulations the array offers a very good polarization purity; i.e. the axial ratio is less than 0.5 dB at broadside. Also, measurements for this array suggest that port isolation values can reach 50 dB, which is consistent with the full-wave simulations. Further work includes additional measurements and characterization of the proposed array.

ACKNOWLEDGMENT

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 709372. Also, the authors would like to indicate that the work is only the authors' views, and that the Horizon 2020 Agency is not responsible for any information contained in the paper. Authors would also like to thank the Heriot-Watt University Technical Workshop and Jérôme Sol, from the Institut d’Électronique et de Télécommunications de Rennes, for prototype fabrication and measurements.

REFERENCES

[1] AA. D. Droitcour, O. Boric-Lubecke, V. M. Lubecke, J. Lin, and G. T. A. Kovacs, “Range correlation and I/Q performance benefits in singlechip silicon Doppler radars for non-contact cardiopulmonary monitoring”, IEEE Transactions on Microwave Theory and Techniques, March 2004.

[2] E. F. Greneker, “Radar sensing of heartbeat and respiration at a distance with applications of the technology”, IET Conference Proceedings, January 1997.

[3] P. D. Hilario Re, S. K. Podilchak, S. Rotenberg, G. Goussetis, J. Lee, “Retrodirective antenna array for circularly polarized wireless power transmission”, 11th European Conference on Antennas and Propagation, 2017.

[4] M. Klotz and H. Rohling, “A 24 GHz short range radar network for automotive applications”, CIE International Conference on Radar Proceedings, 2001.

[5] E. Ahmed, A. M. Eltawil, “All-digital self-interference cancellation technique for full-duplex systems”, IEEE Transactions on Wireless Communications, vol. 14, no. 7, July 2015.

[6] M. Berg, R. UR Rahman Lighari, T. Tuovinen, E. T. Salonen, “Circularly polarized GPS antenna for simultaneous LHCP and RHCP reception with high isolation”, 2016 Loughborough Antennas & Propagation Conference (LAPC).

[7] X. Z. Lai, Z. M. Xie, Q. Q. Xie, X. L. Cen, “A dual circularly polarized RFID reader antenna with wideband isolation”, IEEE Ant. and Wireless Prop. Letters, Vol. 12, 2013.

[8] C. Zhang, X. Liang, X. Bai, J. Geng, R. Jin, “A broadband dual circularly polarized patch antenna with wide beamwidth”, IEEE Antennas and Wireless Propagation Letters, Vol. 13, 2014.

[9] G. Matthaei, L. Young, E. M. T. Jones, “Microwave filters, impedance-matching networks, and coupling structures”, Artech House, 1980.

[10] D. M. Pozar, “A review of aperture coupled microstrip antennas: History, Operation, Development, and Applications”, May 1996.

[11] R. Garg, I. Bahl, M. Bozzi, “Microstrip lines and slotlines”, Artech House, third edition, 2013.

[12] Keng-Chih Lin, Yi-Cheng Lin, “Isolation enhancement of dual-polarized slot-loop antennas for MIMO applications”, 2012 IEEE Radio and Wireless Symposoium.