Monolithic patch antenna for dedicated short-range communications

O. Leonardi, M. Pavone, T. Cadili, G. Sorbello and T. Isernia

Dedicated short-range communications (DSRCs) is a novel short- to medium-range wireless protocol designed for automotive use. The DSRC signals are circularly polarised and allocated in the 5.8 GHz band. Described is the development of a monolithic and compact patch antenna with left-hand circular polarisation intended for the on-board unit equipment of a DSRC system. The 40×60×2.455 mm fabricated prototype exhibits a circularly-polarised gain of about 5.52 dBc with a cross-polar discrimination of about 20 dB.

Introduction: Circularly-polarised waves have many advantages for short-range communication, as they can be used to reduce the interference due to reflections and allow a polarisation match independent of the antennas' angular orientation. In fact, the wireless communication standard known as Dedicated Short-Range Communications (DSRC) [1], used for automotive applications like electronic toll collection, employs circularly-polarised antennas. The EN12253 standard [1] specifies the antenna requirements for the on-board unit (OBU) of a DSRC system. For the OBU a cross-polarisation discrimination (XPD) greater than 10 dB in boresight direction and greater than 6 dB within the −3 dB area are required, moreover a reduced size and a low cost are mandatory.

In the literature there are several examples of circularly-polarised antennas in the 5.8 GHz range that satisfy the conditions stated in the standard, but these antennas are often not monolithic structures [2] and therefore they are not suitable for series production. On the other hand, simpler configurations (for Road Side Units where compactness is not mandatory) make use of antenna arrays and sequential rotation to meet the characteristics required by the standard [3]. In several applications, miniaturisation is a great advantage and there are several examples of small-size patch antennas at frequencies other than 5.8 GHz that are both monolithic [4] and suspended [5]. A 5.8 GHz DSRC-compliant antenna has been reported in [6], wherein, however, the proposed suspended-patch non-monolithic solution requires an ad-hoc feeding network with power divider and branch coupling lines resulting in the use of extra board area. To the best of our knowledge, a circularly-polarised, miniaturised and monolithic antenna compliant with the DSRC system has not been proposed so far: in [7] a monolithic linear polarisation antenna, with 3dB polarisation loss, is proposed and in [8] a DSRC patch antenna is designed (on a substrate with height h=3.2 mm and permittivity ε_r=2.2), for a total height of 4.7 mm.

In this Letter, we report on the development of a microstrip patch antenna suitable for integration on a circuit board. The antenna is realised in a monolithic configuration with a reduced total height and area.

Proposed antenna: The circularly-polarised antenna is designed and realised on Arlon 450, a substrate with relative permittivity ε_r=4.5 and tanδ=0.0035. Arlon 450 represents a good alternative to standard FR4, since it has the same permittivity with a very stable behaviour at higher frequencies and a better loss tangent.

The proposed configuration is a slot-coupled patch antenna, the two substrates have the same permittivity with different height h_1= 0.78 mm and h_2=1.57 mm, respectively. The antenna has been designed with a total size of 40×40×2.455 mm to achieve circular polarisation with axial ratio (AR) lower than 3 dB at 5.8 GHz.

The layout antenna and parameters are shown in Fig. 1. The 50 Ω feeding microstrip line is placed on the 0.78 mm-thick layer, while the radiating patch is realised on the 1.57 mm layer. The microstrip feed line and the slotted ground plane are etched on the opposite sides of the first substrate and the feeding structure (strip and slotted ground plane) is assembled to be centred below to an almost square patch printed on the second substrate. The common ground plane has a cross-slot with slightly unequal slot lengths and 45° inclined with respect to the microstrip feed line. For ease of fabrication and assembly, the same slotted ground plane has been replicated on the 1.57 mm-thick substrate, but the two grounds electrically form a single metal layer. In this regard, for an industrial series production the real final layer stack-up should be considered for fine tuning of CP and some correction steps should be carried out to correctly consider epoxy.

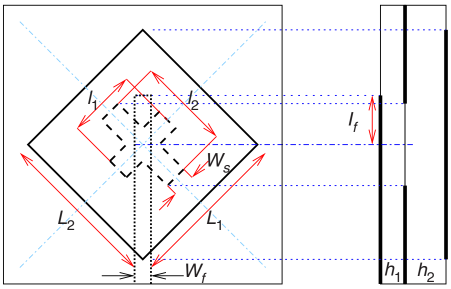

Fig. 1 *Antenna layout front and side view*

A continuous line is used for the patch, a dashed line for the slot in the ground plane, and a dotted line for the 50 Ω feeding microstrip. L_1=9.85 mm, L_2=10.4 mm, l_1=5.8 mm, l_2=5.4 mm, w_s=1.7 mm, w_f=1.5 mm, l_f=3.8 mm

Antenna optimisation and experimental results: The antenna has been optimised by means of numerical simulation in order to achieve circular polarisation with axial ratio lower than 3 dB at 5.8 GHz. The CP is obtained exciting two orthogonal modes with equal magnitudes and in phase quadrature. Different patch lengths, L_1 and L_2, and slot lengths, l_1 and l_2, are used to balance the mode amplitudes as well as to control their phase difference. The stub length, l_f, can be adjusted to match the antenna. The operation frequency is determined by patch size. Fig. 2 shows how a 50 μm differential or common mode variation of L_1 and L_2 influences the $|S_{11}|$.

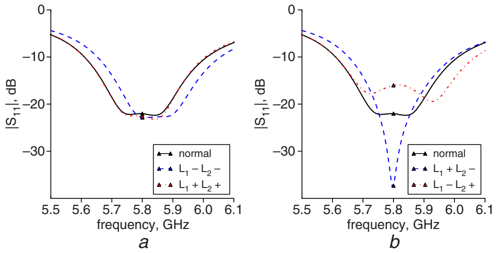

Fig. 2 *$|S_{11}|$ against frequency for 50 µm variations in patch dimensions*

a L_1 and L_2 common mode increase/decrease
b L_1 and L_2 differential mode increase/decrease

To easily mount a SMA-connector it was decided to increase the 0.78 mm-thick substrate of 2 cm along the *y*-axis, thus achieving a layout with a total size of 40×60 mm. The measured and simulated S-parameters, $|S_{11}|$ against frequency, and input impedance are shown in Figs. 3*a* and *b*, respectively, where it is possible to observe that the realised antenna is well matched from 5.6 to 6 GHz for a 6.89% impedance bandwidth.

The simulation results are in good agreement with the experimental measurements. The simulated curves are reported for both the realised 40×60 prototype and the 40×40 reference design. The gain patterns of the proposed antenna were measured in an anechoic chamber using a linearly polarised incident wave and the results are in good agreement with the simulation results. A LHCP gain of about 5.52 dBc was estimated by the gain-comparison method. Fig. 4*a* reports the measured and simulated gain pattern for a linearly polarised incident wave along different directions. Here it is possible to see that the experimentally measured patterns are closer than those simulated, witnessing a good CP. Fig. 4*b* shows the experimentally measured polarisation ellipse in the boresight direction at 5.8 GHz. A linearly-polarised incident field is considered and the detected signal is plotted against the OBU antenna rotation from 0° to 180°. From the latter Figure it is possible to extrapolate an axial ratio of about 1.7 dB, which corresponds to an XPD of about 20 dB. These values meet the standard requirements and are obtained with a very compact design which is required for a small device such as the OBU in an electronic toll collection system. To estimate the CP frequency bandwidth the boresight normalised gain against frequency is plotted in Fig. 5 with different relative orientations between the antenna and the linearly polarised incident field.

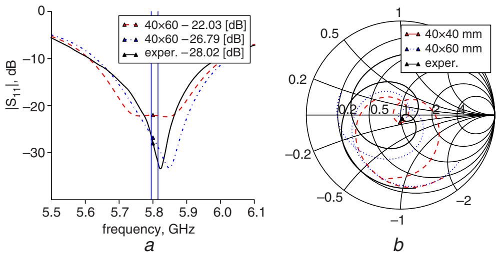

Fig. 3 *Measured and simulated impedance bandwidths*

a Experimental and simulated $|S_{11}|$; vertical lines show the DSRC band
b Input impedance on Smith chart

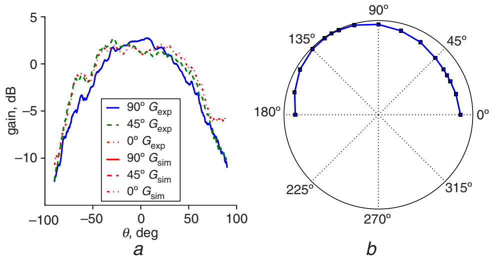

Fig. 4 *Far-field measurements*

a Measured and simulated gain pattern for linearly-polarised incident electric field at 0°, 45° and 90°. 3 dB polarisation loss not compensated
b Measured polarisation ellipse, electric field magnitude against angle, in boresight direction at 5.8 GHz

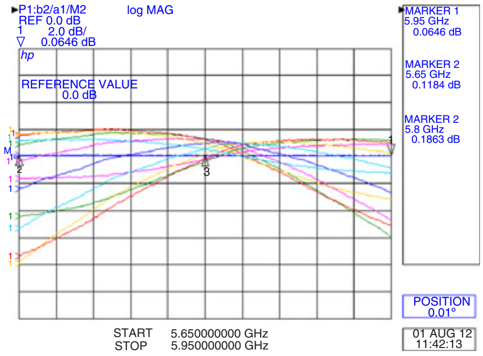

Fig. 5 *Boresight gain against frequency*

Curves normalised to reference one and taken with test antenna rotated from 0° to 180°

Conclusion: In this Letter a compact monolithic patch antenna for DSRC applications has been introduced and optimised by simulations. Despite the compactness of the design the experimental characterisation confirms that requirements enforced by the DSRC standards are met, and a circular polarisation with a XPD as large as roughly 20 dB is achieved.

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One or more of the Figures in this Letter are available in colour online.

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