Evaluation of Planar Elliptical Antenna Array with Inner Counter-Elliptical Slot

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Abstract. *This paper presents and analyzes a low profile planar antenna array of elliptical elements with inner counter-elliptical slots. The antenna has single feed and provides two main directive radiation components (front and back), with gain higher than 7 dBi and circular polarization (CP) over the entire 5 GHz ISM& UNII bands. This approach also cancels the null over the elevation plane, which makes it suitable for bidirectional communications, also for proximity coverage. The inner slot of elliptical shape provides three additional degrees of freedom to match the planar monopole and/or array in impedance and polarization over the desired frequency band. An electromagnetic (EM) model of the proposed antenna is developed for numerical analysis and optimization. The principle of operation and parametric study of the antenna are provided. The antenna is fabricated and experimental results are presented. The number of elements in the array are chosen according to the desired gain and the inner elliptical slot parameters (major radius, elliptical ratio and rotation) scaled for impedance and polarization matching.*

Keywords

Axial Ratio (AR), Circular Polarization (CP), front-back radiation, Planar Elliptical Antenna Array (PEAA), Planar Elliptical Monopole (PEM), wide bandwidth

1. Introduction

Nowadays we are witness to a growing demand of everywhere availability of wireless technologies. For this the use of multi-band or wide band antennas that accommodate different communication systems is fundamental. According to the system and the application, different radiation patterns (RP) can be preferred to others. Besides RP, polarization is another important characteristic to be taken into account for wireless systems [1].

In general, the base station antennas in micro cellular systems for urban areas are located lower than the surrounded buildings along the streets, being the communicable cell formed along the street. For these environments, the omnidirectional RP is degraded when it is placed closed or attached to the wall or metal. If a bidirectional antenna is applied, the deterioration of the omnidirectional antenna performance can be reduced or even avoided. Therefore, the developments of UWB antennas possessing bidirectional pattern are desirable for inter vehicular communications (IVC).

Another important point to have in consideration is the environmental driving conditions where vehicles often circulate in highly reflective infrastructures (e.g. tunnels or bridges) and adverse weather conditions (e.g. rain, fog, snow). For communication in these environments circular polarization (CP) is preferred. CP allows signal transmission/reception in all planes, it overcomes out-of-phase problem which can cause dead-spots and it is more resistant to signal degradation due to adverse weather conditions [2].

The analysis of all these requirements (RP, bandwidth and polarization) led us to the definition of our goals: to design a low-profile bidirectional antenna with CP in order to be used for 5.9 GHz IVC also as for all 5 GHz UNII/ISM bands which can be used for IEEE 802.11a (5.15–5.35 GHz and an additional band of 5.725–5.825 GHz), and HiperLAN2 (5.47–5.725 GHz).

In literature single feed antennas CP has been induced by several approaches such as: different radiating structures (e.g. fractal, spiral, dielectric resonator) [3], [4]; modification of radiation elements geometry (e.g. slots insertion, trimming opposite corners) [5–7]; or ground plane modifications (e. g. stub insertion) [8], [9]. When a scalable gain is desired, arrays with a correct feeding network need to be designed. A good analysis of several feeding networks is presented in [10]. An interesting approach to scale the gain is presented in [11] based on omnidirectional microstrip antenna arrays (OMAA), however it is presented with low bandwidth and linear polarization.

Defining our problem as design of a low cost, bidirectional, scalable antenna with CP for 5 GHz bands, several shapes were analyzed, although, none satisfied all requirements.

The research started by analyzing planar monopoles known by their broad band and simple manners to improve their CP bandwidth. It was verified that a planar elliptical monopole (PEM) with an inner elliptical slot can provide relatively wide CP covering our band of interest. Moreover, the three matching parameters of the inner elliptical slot (major radius, elliptical ratio ((Major Radius)/(Minor Radius)) and rotation) provide an easy way of performing phase correction. Another advantage of this PEM is that it can be easily implemented into a series array (as similarity of [11]) in order to provide a bigger front-back gain.

In this paper a PEM is studied and applied into an array of three elements, leading to the development of the CP Planar Elliptical Antenna Array (CP-PEAA) initially presented in [12]. Besides a good front-back radiation the array also has the advantage of removing the null over the elevation plane. Practical and real implementations can be addressed for long range bidirectional (e. g. tunnels, traffic lights, IVC) and proximity (e. g. WiFi) communications.

Based on the previous description, this paper is organized as follows: Section 2 briefly presents PEM structure with an inner elliptical slot. It is followed by Section 3 where the CP-PEAA with three elements is described. In Sec. 4 the comparison between simulated and measured antenna results are described. Finally, some conclusions are presented in Sec. 5.

2. Planar Elliptical Monopole (PEM)

Planar monopoles are characterized by their wide bandwidth and can have different geometries such as: triangular, rectangular, pentagonal, circular and elliptical, as presented in [13]. However, the polarization is in majority linear and the RP omnidirectional.

To impose the two orthogonal current components for CP in single feed monopoles, ground plane modification (i.e. insertion of stubs) and/or changes in the feeding position are common used techniques.

For the special case of the planar elliptical monopole (PEM), another way to perform this task, without changing the feeding position, can be done by rotating the radiating element. For a single element both approaches (changing feeding position or rotating the radiating element) are valid, however, if we consider a series array, where ground perturbation is not available in all radiating elements for current phase correction, the first approach can't be applied. On the other hand, the second approach (rotation of the radiating element) proved to be insufficient for array implementation with CP over the entire 5 GHz bands. The solution for this problem can be overcome with the insertion of an inner slot in each radiating element providing an individual current correction factor.

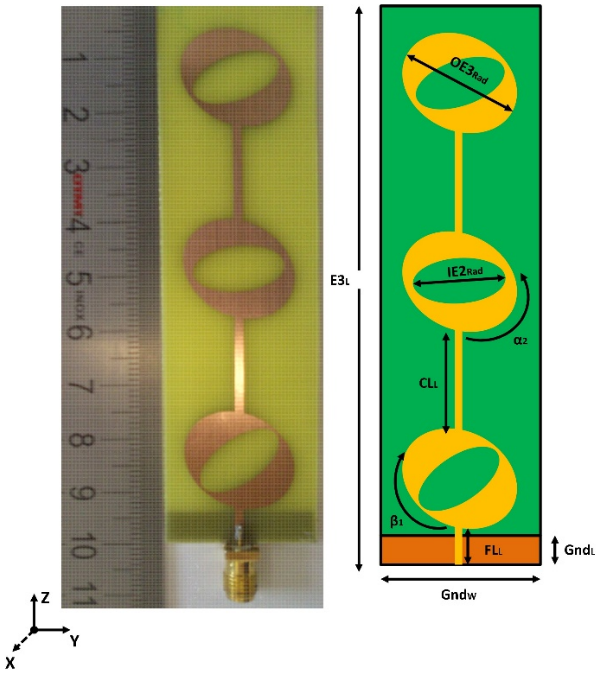

Fig. 1. CP-PEAA antenna design.

Variable	Dimension	Description
CL_L	17.25 mm	Connecting Line Length
$E3_L$	100 mm	Antenna Length
FL_L	12 mm	Feed Line Length
FL_W	1.7 mm	Feed Line Width
Gnd_L	5.5 mm	Ground Length
Gnd_W	28 mm	Ground Width
$IE_N Rad$	8.3,8.3,8.3	Inner Ellipse *N* Major Radius
$IE_N Ratio$	0.5,0.5,0.5	Inner Ellipse *N* Ratio
α_N	35^o,5^o,20^o	Inner Ellipse *N* Rotation
$OE_N Rad$	8.5,8.5,8.5	Outer Ellipse *N* Major Radius
$OE_N Ratio$	1.25,1.25,1.25	Outer Ellipse *N* Ratio
β_N	60^o, 60^o, 60^o	Outer Ellipse *N* Rotation

Tab. 1. CP-PEAA dimensioning.

Starting by a circular monopole, it provides linear polarization and quasi-toroidal RP with a single optimization parameter, circular radius. Varying the circular to elliptical shape, two degrees of freedom are added, the elliptical ratio and rotation. This provides the chance to slightly change the RP and polarization. More degrees of freedom can be added with the insertion of an inner slot. For our design the slot was implemented with counter-elliptical shape. This design avoids sharp transitions and the addition of three optimization parameters (3Rs), inner major Radius, elliptical Ratio, and Rotation. All together six optimization parameters are available, three for the outer ellipse plus three for the inner elliptical slot.

The analyzed PEM is dimensioned according to the lower radiating element of the CP-PEAA presented in Fig. 1 and described in Tab. 1.

To design the CP-PEM with the inner counter-elliptical slot, it is important to know the influence of its three design parameters: major radius, elliptical ratio and rota-

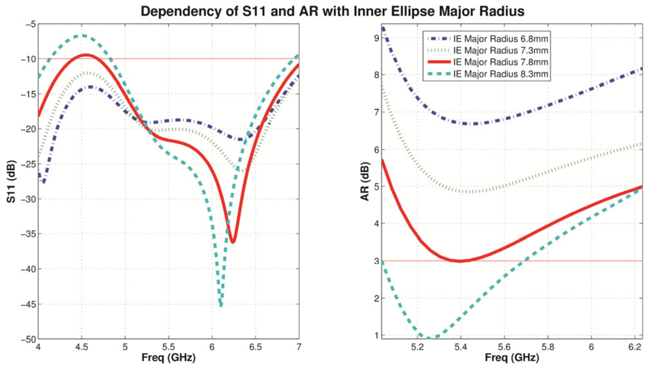

Fig. 2. S_{11} and *AR* dependency with IE Major Radius.

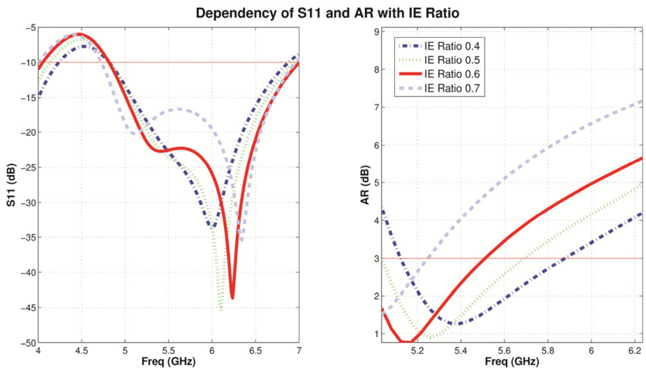

Fig. 3. S_{11} and *AR* dependency with IE ratio.

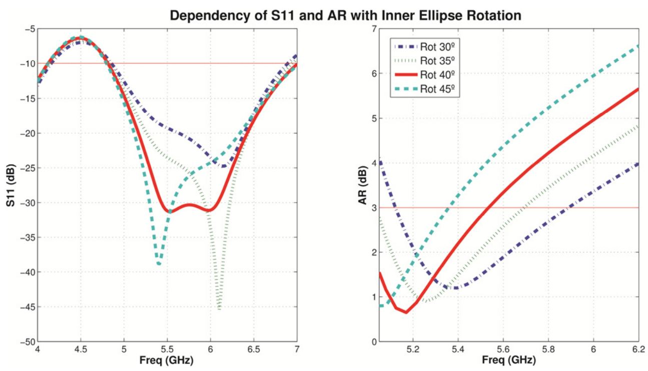

Fig. 4. S_{11} and *AR* dependency with IE rotation.

tion (3Rs). The dependency of S_{11} and *AR* with the 3Rs in presented in Figs 2, 3 and 4. It is clearly verified that while inner elliptical ratio and rotation slightly shift the AR, the radius variation has a main impact on polarization matching.

For the analyzed variation, it can be seen that the three parameters significantly influence the impedance and polarization matching. Controlling these 3Rs parameters a well matched PEM can be designed, providing the base for the CP-PEAA presented in the next section.

3. CP-Elliptical Antenna Array (CP-EAA)

The PEM can provide CP although, with relative low gain (~2 dBi) for the desired application (front-back gain

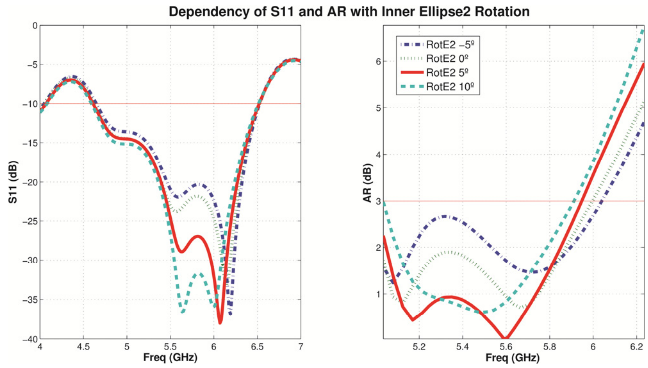

Fig. 5. S_{11} and *AR* dependency with IE2 slot rotation.

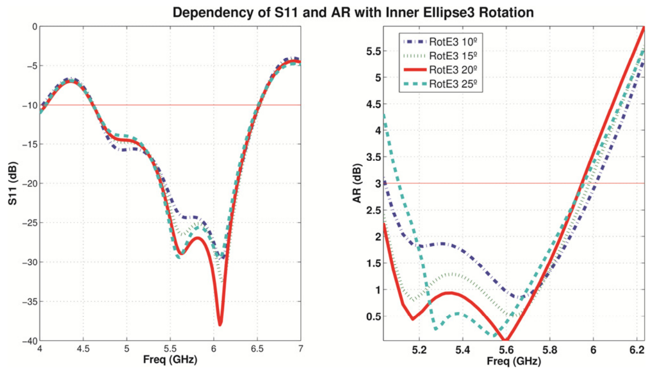

Fig. 6. S_{11} and *AR* dependency with IE3 slot rotation.

higher than 7 dBi). To improve and achieve the desired gain a series array of three elements is analyzed, as shown in Fig. 1. The antenna dimensioning after optimization is presented in Tab. 1.

Figure 1 shows the geometry of the proposed CP-PEAA. The antenna is printed on 0.787 mm-thick FR4 ($\varepsilon_r = 4.1$, $\tan\delta = 0.02$) substrate with 100×28 mm^2.

As a starting point for comparison all the array elements with the parameters (major radius, elliptical ratio and rotation) identical to the CP-PEM presented in Sec. 2 were considered. With these characteristics a good impedance matching was achieved, although with poor CP over the band of interest, 5.2–5.8 GHz. In order to improve the AR, a rotation of the inner elliptical elements 2 and 3 was performed for optimization. The impact of these parameters on S_{11} and *AR* is presented in Figs. 5 and 6.

For this analysis all the other parameters (ground, feed and connecting lines) are described in Tab. 1. After a careful analysis of the simulation an antenna for testing was developed, presented in the next section.

4. Measurements

This section presents a comparison of simulated and measured results of the built antenna. The simulation results were performed with ANSYS HFSS software package [14]. Figure 7 presents the antenna S_{11} comparison analysis. Next we analyze the XY plane left and right hand circular polarization (LHCP and RHCP) RP for 5.2 GHz and

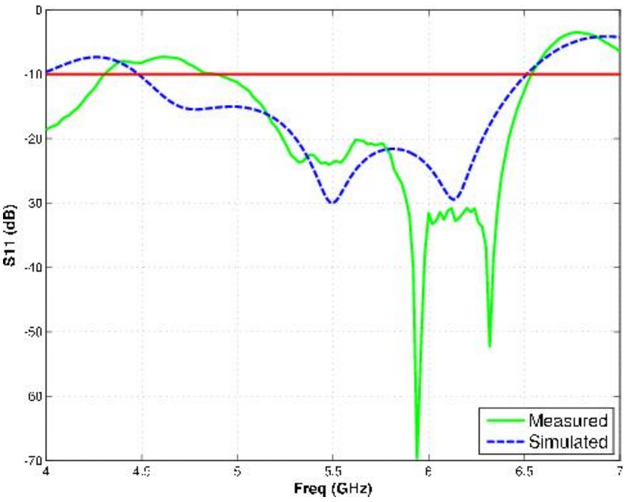

Fig. 7. S_{11} comparison.

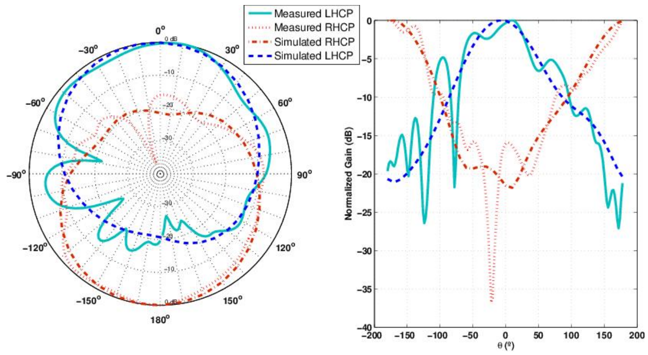

Fig. 8. XY plane, LHCP/RHCP radiation pattern for 5.2 GHz.

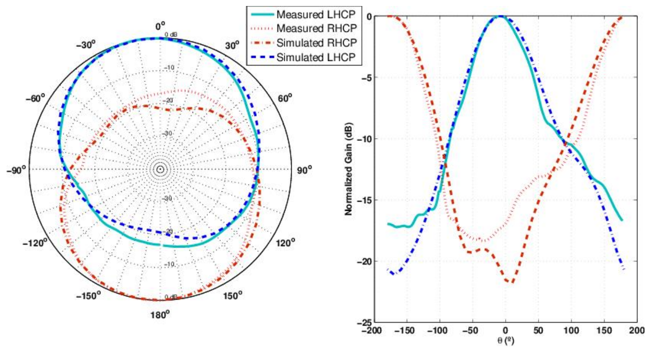

Fig. 9. XY plane, LHCP/RHCP radiation pattern for 5.8 GHz.

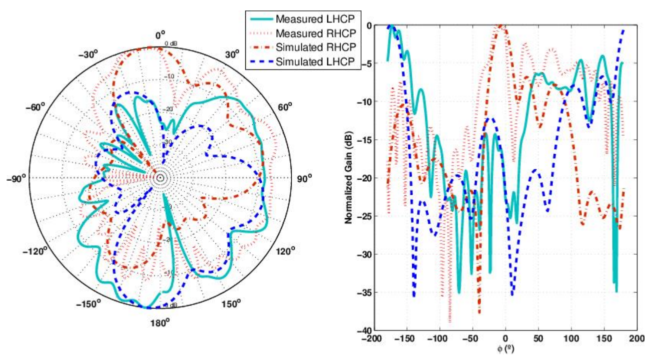

Fig. 10. YZ plane, LHCP/RHCP radiation pattern for 5.2 GHz.

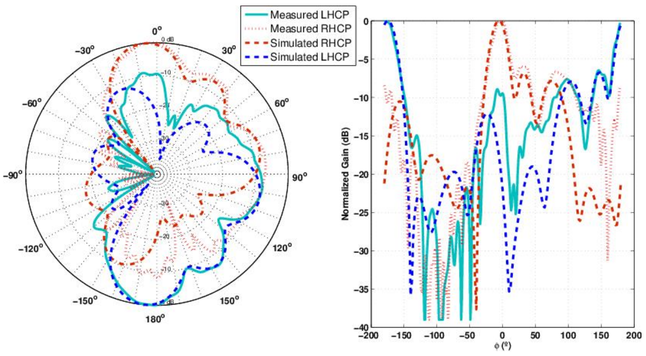

Fig. 11. YZ plane, LHCP/RHCP radiation pattern for 5.8 GHz.

5.8 GHz, presented in Figs. 8 and 9. The 180° presents the front side of the antenna, radiating RHCP and the 0° the back side. The YZ plane is presented in Figs. 10 and 11, where 90° represents the upper side of the antenna. The measured gain for XY plane was 7.1 dBi and for upper side of YZ plane it was 6 dBi with vertical polarization.

The AR over the operation band for the front and back sides is also analyzed. The agreement between simulation and measured results is obvious, although, some deviation can be seen which can be partially justified by the FR4 characterization.

5. Conclusion

In this paper a new printed planar microstrip antenna with elliptical elements is presented and measured.

The operating bandwidth of the antenna with usable RP is about 20%. A new way to match PEM with CP is proposed by the insertion of an inner counter-elliptical slot.

This technique provides wide band in polarization for single feed monopoles and can be easily integrated into arrays named here PEAA. To compensate the mismatch of polarization inherent to the array implementation, rotation of the inner counter-elliptical slot can be used as an easy way of optimization. The proposed antenna provides two main directive radiation components (front and back) with gain higher than 7 dBi, and CP over the 5 GHz bands with three radiating elements. Higher gain is possible with the integration of more radiating elements.

This antenna can be suitable for performing both inter-vehicular and proximity WiFi communication.

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