Combination of Leaky and CPW Modes for Leaky Lens Antennas with Dual Polarization

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Abstract—This work presents for the first time a dual polarized leaky lens antenna. The non dispersive performances of linearly polarized leaky lenses are maintained while doubling their aperture efficiency. In fact two orthogonal incoming polarizations can be received with same phase center, while the leaky lens retains the lowest cross polarization levels reported for UWB antennas. The achievement of these goals is obtained despite the complete planarity of the feeding structure. Twin slot lines are used as both transmission and leaky lines, by exploiting the coexistence of both common and differential modes. The design has then been validated by means of full wave simulations. Future applications will include radiometric or spectroscopic scenarios in which accurate polarization discrimination is required.

I. INTRODUCTION

Ultra wide band (UWB) antennas have been extensively studied in the last ten years, since they ideally fulfill the requirements of multi-functionality applications, and allow systems that support large instantaneous bandwidths. An important antenna feature that still could be improved in a number of UWB systems is the quality of the polarization purity, especially when the antenna should be able to support dual polarization.

In [1] and [2], it was demonstrated that slotted leaky wave antennas can be combined with lens (receiving the name of leaky lens antennas) to focus the radiation of the leaky modes to a broadside direction and to increase substantially the directivity of the antenna. These antennas can be fed in coplanar technology and they are good candidates for future UWB applications since they have demonstrated to provide a huge band of operation with a stable radiation pattern and a non-dispersive response.

With respect to other competitive UWB antennas, such as [3], [4] and [5] the leaky wave feeds present planar feed structures, with coplanar waveguide (CPW) feeding that reduces its complexity and the costs of manufacture.

One limitation of the leaky lens antenna proposed in [1] and [2] was that these antennas could only operate at one linear polarization. With the present work, we propose a possible solution to this limitation resorting to two parallel slots and a symmetric configuration, in which both Coplanar Waveguide (CPW) and leaky modes are exploited.

Based on this characterization an antenna design of a dual polarized antenna which works with high efficiency and excellent polarization purity on a BW 1:3 is eventually proposed. The design is validated with numerical results obtained with commercial a software based on a FDTD method.

II. DUAL POLARIZED LEAKY ANTENNA SCHEME

In this Section, the dual polarized feed scheme is presented. The proposed antenna derives in essence from the work developed in [6] and [7], related to slot leaky wave antennas. A basic configuration of this leaky wave antenna is illustrated in Fig. 1, and it is essentially composed by two metal plates with a slot in the middle that is fed with a differential source (S1). These pieces of metal are printed being the interface between two dielectric materials (above and below) which have different dielectric constant (i.e. $\epsilon_1 > \epsilon_2$).

![Fig. 1. General configuration of a slot leaky wave antenna composed of two metal plates in between two different dielectric materials.](image-url)

The properties of the slot remain almost unchanged if instead of one slot there are two (electrically close) where each of these slots is fed with the same phase. The configuration of the leaky antenna is in this case a co-planar waveguide transmission line, with the important difference that in the latter, the phase of the feeding at the slots needs a 180° difference in order to confine the fields along the structure. Accordingly a two-slots configuration supports two diverse modes of operation:

- Leaky mode: In which the phase of the excited electric fields are the same in both slots (Fig. 2.a).
• CPW mode: In which the phase of the excited electric fields are opposite in both slots (Fig. 2.b).

Then, a dual polarization leaky wave antenna can be achieved as illustrated in Fig. 3, in such a way that four branches are defined. For the first polarization, the left and right branches (which have 180° phase difference, one with respect to the other) are used as CPW transmission lines in order to feed the upper and lower branches that constitute the first double slot leaky antenna. For the second polarization, the upper and lower branches (which also have 180° phase difference) work as transmission lines to feed the left and right branches that constitute the second double slot leaky antenna.

III. ANTENNA DESIGN

In this section we will show an example of design of this dual polarization leaky lens antenna which work from 3 to 9GHz (BW 1:3). The first step in the design should be the development of an adequate transition between the CPW lines and the leaky slots. Even if the transition between modes is matched, the optimal width of the slots for obtaining an adequate radiation can require a reduction of its size at the end of the slots for a reduction of the characteristic impedance.

These impedance considerations are out of the purpose of this paper, and for simplicity of the reading, we will not enter in their details, considering that they were properly addressed.

For instance, we are going to consider the configuration: \( w_s = 0.05 \text{mm}, \ d = 0.7 \text{mm} \) and \( b = 0.6 \text{mm} \). As commented, since the impedance at each of the two CPW lines constituting one of the two polarizations of the antenna is approximately 200 \( \Omega \) for these dimensions, these lines must also be tapered at their outer ends where the ports are located. By using a end-taper (which must be longer than \( \lambda_r / 4 \), where \( r \) means the dielectric of the lens, at the lowest frequency of the defined operation), this impedance can be reduced to lower values, for instance, 70 \( \Omega \).

As shown in Fig. 4 the antenna is well-matched on a band 3 to 10 GHz, with return losses lower than 1 dB. However if one could accept slightly higher return losses, in the order of
2.5 dB, the antenna could be used from 2 GHz which would imply an effective BW of 1:5.

![Fig. 4. Return losses associated to the input impedance match at each 70 Ω port.](image1)

The upper frequency limit in using the antenna does not derive from the CPW/Leaky impedance matching, but from the amount of radiation losses of the CPW feeding that will perturb the radiation pattern.

Before proceeding with the lens design and the pattern analysis, it is useful to mention that the $S_{12}$ (or coupling between the two polarized ports) has been not studied, since by definition is equal to 0 (if a phase of 180° is achieved between the two branches of the same polarization). The practical implementation might include some imperfections which cannot be meaningfully included in a numerical simulation.

A. Lens Shape

As an alternative to an elliptical dielectric lens the combination of a hemisphere and cylinder is usually adopted [8], [9], [2]. In the present case the hemisphere was chosen with diameter $D = 205$ mm and the extension length of the cylinder was chosen $h_{ext} = 32.4$ mm. The use of matching layers to reduce the reflections between the lens and the external air is also proposed. In [10] a $\lambda/4$ configuration of three layers was proposed, and in [1], the author proposes an ultra wide band solution in which the distances between the three matching layers were optimized. Following the same procedure as in [1], we have obtained a configuration of matching layers which works from 2 GHz to 10 GHz as it is illustrated in Fig. 5 (with an inset which shows the configuration). The dielectric materials are $\epsilon_r = 2.5$, $\epsilon_r = 3.5$ and $\epsilon_r = 6.5$; and the respective heights are $h_1 = 4$ mm, $h_2 = 7$ mm and $h_3 = 9$ mm.

B. Radiation properties:

The radiation properties of the antenna, obtained with a FDTD Method, are now discussed. The gain of the radiation pattern increases almost linearly with the frequency as was the case in the singly polarized antenna described in [2]. The cross polarization is not plotted in this figure since it is negligible in the main planes, however it deserves our attention since it has its maximum close to the diagonal plane ([2]). In Fig. 6 is illustrated the evolution of the gain with the frequency, the radiation efficiency and the corresponding maximum level of cross polarization. The latter has an increase tendency with frequency, although it is lower than -15dB for all the band, which is an indication that the proposed antenna will discern properly the two orthogonal polarizations. The radiation efficiency (excluding matching losses) is approximately -1dB for all the band, that is essentially power which cannot be radiated since it has an elevation angle lower the critical angle.

![Fig. 5. Reflection coefficient for the proposed matching layers.](image2)

![Fig. 6. Gain, radiation efficiency and maximum level of cross-polarization.](image3)

IV. CONCLUSIONS

An innovative feeding for leaky lens antennas has been proposed. This feeding allows an dual polarization radiation with an elegant combination of co-planar leaky radiating lines and co-planar CPW transmission lines. Fine tuning of the transition between the guiding and radiating lines allows for designs that cover the BW 1:5 with efficiencies higher then 70% or BW 1:3 with efficiencies higher than 80%. Even more important than the efficiency are the quality of the patterns and the phase center stability that make this antenna
suited a candidate for UWB dual polarized feed for high performance reflectors. In fact the mutual coupling between the two ports for the orthogonal polarizations is nonexistent and the cross-polarization at each port is lower than -15 dB for the whole band. A specific example is designed for the frequency range 3 GHz to 9 GHz so that colleagues could compare the expected performance from this antenna with existing solutions. Possible example of application is of course the Square Kilometer Array, however there is no reason why this very same structure could not be simply scaled at much higher frequencies (THz), where lenses are routinely used as reflector feeds.

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REFERENCES


