DESIGN GUIDELINES FOR THE UWB PYRAMID ANTENNA

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ABSTRACT

In this paper a novel UWB directive and non dispersive lens antenna is presented. It is based on the broad band leaky wave radiation occurring at a slot printed between different homogeneous dielectrics. This paper presents the guidelines for the UWB design, the hardware demonstrator and pertinent measurements. The main motivation for this work was the development of a field sensor for electromagnetic compatibility to be used in the range 4-40 GHz.

1. INTRODUCTION

Several fields could potentially benefit from the development of extremely broadband directive antennas. For example the ultra-wide band (UWB) frequency range 3.1-10.6 GHz, regulated by the Federal Communication Commission (FCC), demands for transmission and reception systems capable to guarantee very little distortion of the signals (i.e. flat magnitude and linear phase of the transfer function represented by the transmitting/receiving antenna). The discipline of electromagnetic compatibility (EMC) also presents formidable reasons to realize field sensors operating efficiently in broad and wide frequency ranges, especially with the exponential development of the Ku and Ka bands for telecommunication satellites and for the growing interest for the 60 GHz Wireless Local Area Networks (WLAN). With specific reference to the EMC field measurements, the antennas tend to be the bottle neck at high frequencies for the following three reasons:

1. The antenna should have a significant directivity in order to perform radiated field measurements without perturbing significantly the device under test.
2. The same antenna should be operating over a wide range of frequencies, with minimal phase distortion, in order to allow for real time measurements (with minimum antennas replacement).
3. It should be possible to integrate the antenna with electro-optical converters so that the measurements can be performed at locations very distant from the measurement environment. This because the actual signal is transported via loss-less fiber optics rather than with coaxial cables that are extremely lossy at frequencies higher than 10 GHz.

Unfortunately an ultra wide band (UWB) antenna with a resistive constant impedance and high directivity had not been realized until now. All existing broad-band antennas suffer from various kind of limitations. One of the most successful examples, the Vivaldi antenna, typically trade off the bandwidth with the cross polarization level and the phase center stability, [1], [2]. Even more so when the aim is high directivity as in the Long Tapered Slot (LTS) configurations[3]. In [4] these problems seem to be solved with a brilliantly arranged log periodic antenna but its directivity is moderate (11dB).

If one needs higher directivities at higher frequencies and wants to integrate the antenna with MMIC's (or electro-optical converters for EMC applications), a simpler lens configuration can be realized and it is presented in this paper. This work is an extension of [5], where a novel type of wide band leaky wave antenna has been proposed. Both this latter and the present antenna were based on the frequency independent radiation mechanism occurring on a slot printed at the interface between two different dielectrics. The relevant Green's function has been theoretically investigated in [6] and [7]. If the two media are free space and a dense dielectric, radiation occurs primarily in the dielectric. This type of propagation does not suffer from the typical dispersion effects that characterize all previously proposed leaky wave radiation mechanisms. The main idea of this work is to exploit the novel broad band leaky concept to realize a multi-octaves dielectric lens antenna: the Pyramid antenna.

2. ANTENNA DESCRIPTION

The UWB version of the leaky lens antenna concept is depicted in Fig. 1. The lens geometry is the composition of two building blocks: each one of them resembles a single leaky lens antenna [5]. The shape of each one of these dielectric lenses is obtained as union of an infinite set of

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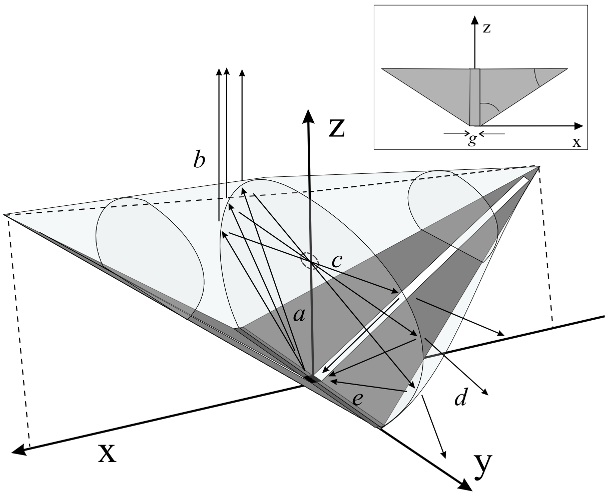


Figure 1. Geometry of the Pyramid antenna with relevant rays in the central cross section. Inset: Side view.

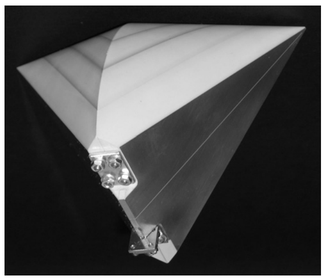
cross section planes of truncated elliptical shape and decreasing dimension. Each of the ellipses contains a slot etched on a ground plane, in the lower focus. The eccentricity of the ellipse is $e = 1/\sqrt{\epsilon_r}$, with ϵ_r the dielectric constant of the lens. In correspondence of the joining of the two slots and of the two original lenses, the shape of each one of the lenses is altered in order to host a ground plane of width g, on $x - y$ plane, see the side view in the inset of Fig. 1. This ground plane hosts the Coplanar Waveguide (CPW) transmission line, that will feed the unique slot that extends under both lenses.

For the sake of convenience the origin of the reference system is in the center of the CPW ground plane. The values of the angles α_t and γ_{LW} are only functions of the lens dielectric constant: $\gamma_{LW} = cos^{-1}\sqrt{\frac{\epsilon_{r1}+\epsilon_{r2}}{2\epsilon_{r2}}}$ and $\alpha = \frac{\pi}{2} - \gamma_{LW}$.

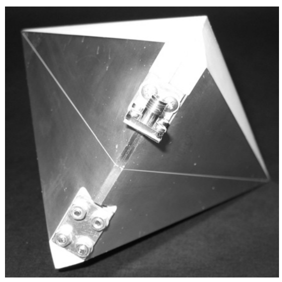
As explained in [7] leaky wave rays in the dense dielectric are originated from each point of a slot etched in a ground plane between two infinite homogeneous dielectrics. Also in the present case, even if the problem is not planar, rays emerge from the slot. For each of the elliptical cross section the chosen eccentricity implies the rays a), b), c), d), e) drawn in Fig. 1 for the central cross section. The different rays are: a) emanated from the slot (lower focus), b) transmitted after the first interface (focusing effect in the far field), c) reflected at the first interface, d) transmitted at the second interface (unfocused), e) reflected at the second interface and refocused toward the slot. The first transmitted rays, that carry most of the power due to small reflection at the lens-air interface, are all focused in one direction. Asymptotically, only doubly reflected rays, that already lost power in the first two transmissions, return back to the focus (slot line). This guarantees that the present lens simulates well the ideally infinite dielectric configuration discussed in [6], characterized by very low frequency dispersivity. Note that the lenses are oriented in such a way that the rays generated in both arms of the unique radiating slot are focused, at least in first approximation, in broad side (z-direction). The antenna is designed to be used in the band ranging from 4 GHz to 40 GHz. In correspondence of the tip of the ground-plane, the shape is altered in order to form a small strip laying on the x-y plane, see Fig. 1. This portion of the ground plane hosts the Coplanar Waveguide (CPW) transmission line with 50 Ohm impedance, feeding the slots that extends on both sides and generating two leaky waves, one along each arm.

3. MANUFACTURING AND MEASUREMENTS

A prototype of the Pyramid antenna was manufactured using TMM 3 (from Rogers) for the lens. The final result is shown in Fig. 2, the lens length, height and width are 18 cm x 10 cm x 7 cm respectively. The CPW line



(a)



(b)

Figure 2. Finals prototype: (a) lens; (b) feeding network.

is as short as possible and reaches on one side of the radiating slot to the SK coaxial connectors. In general, the leaky lens was meant to furnish an integrated receiver, thus the external coaxial connection could be avoided in a real system that would take benefit of the possible integration space at the side of the slot.

3.1. Reflection Coefficient

The first quality parameter of an UWB antenna is the impedance bandwidth. The simulated and measured re-

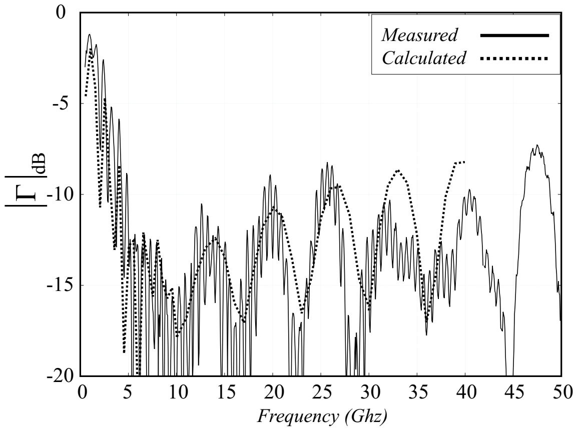


Figure 3. Reflection coefficient simulated and measured at a CPW port located at distance of 1 cm from the CPW-slot intersection. The simulations are pertinent to an equivalent planar structure obtained using the commercial code Ansoft Designer.

flection coefficients of the antenna when fed by a 50 Ohm transmission line are plotted in Fig. 3. The simulated results are pertinent to simulations on an *equivalent* planar structure that could be represented using the commercial Method of Moments tool Ansoft Designer. The CPW port is located at 1 cm of distance from the CPW-slot to represent realistically the distance between the slot and the CPW-coaxial transition. The reflection coefficient is below 9 dB for almost one decade of bandwidth (4-40 GHz). For very low frequencies, the radiating slot is so short in terms of the wavelengths that some power reflected at the end-points alters the input impedance. The broader oscillations are due to the fact that the CPW line has a finite length and the input impedance varies over frequency. The shorter period oscillations are associated to the reflections at the dielectric-air interface.

3.2. Radiation Pattern

The measured radiated fields are reported in figures 4–6.

Fig. 4 shows the co-polar radiation patterns in the H-plane for different frequencies: 4 GHz (dashed-dotted line), 6.4 GHz (dotted line), 16 GHz (dashed line) and 32 GHz (solid lines). This plane is dominated by the leakage radiation and, apart for the lower frequency, the radiation patterns are quite clean and directive and with low side lobe levels. The antenna pattern presents a -3dB angle that shows a limited variation between 6.4 GHz and 16 GHz and then remains constant until 32 GHz.

Fig. 5 shows the co-polar radiation patterns in the E-plane for the same frequencies: 4 GHz (dashed-dotted line), 6.4 GHz (dotted line), 16 GHz (dashed line) and 32 GHz (solid lines). This plane is dominated by the geometrical optics and the patterns present frequency dependence. In both cases, the maximum of radiation occurs always in the same direction.

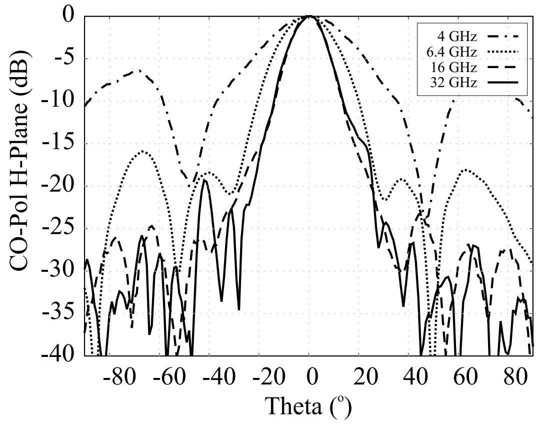


Figure 4. Co-polar radiation pattern in the H-plane for three different frequencies: 4 GHz (dashed-dotted line), 6.4 GHz (dotted line), 16 GHz (dashed line) and 32 GHz (solid lines).

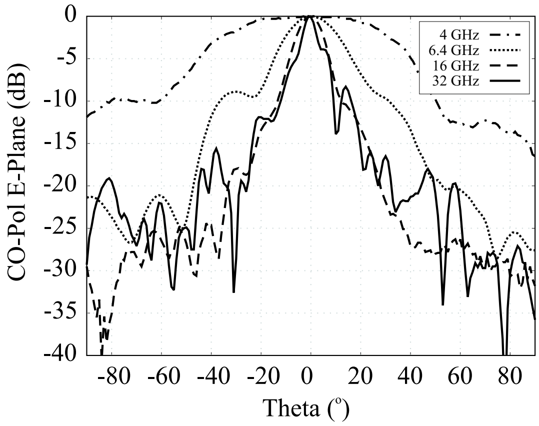


Figure 5. Co-polar radiation pattern in the E-plane for three different frequencies: 4 GHz (dashed-dotted line), 6.4 GHz (dotted line), 16 GHz (dashed line) and 32 GHz (solid lines).

Fig. 6 shows the co-polar and the cross-polar radiation patterns in the diagonal plane for 16 GHz. In this plane the radiation pattern is the combination between the radiation patter in the E and H planes. In the diagonal plane, the Pyramid Antenna has a cross-polarization level of -16 dB within the -10 dB beam width.

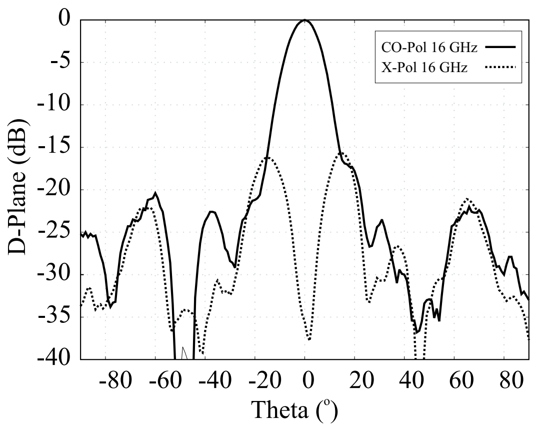


Figure 6. Co-polar (solid line) and cross-polar (dotted line) radiation patterns in the diagonal plane for 16 GHz and 32 GHz.

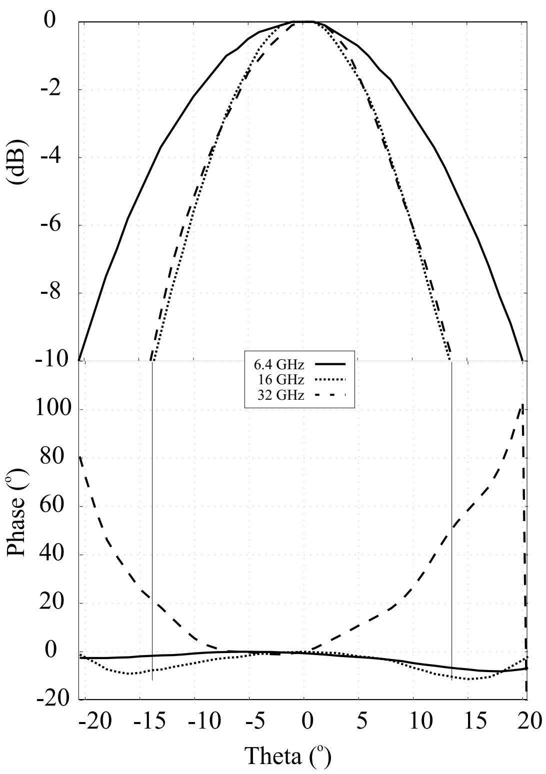


Figure 7. Amplitude (top) and phase (bottom) of the radiated field in the H-plane as a function of the observation angles

3.3. Phase Center

Fig. 7 shows amplitude (top) and phase (bottom) of the radiated field in the H-plane as a function of the observation angles. The phase is substantially constant at 6.4 GHz and 16 GHz. At 32 GHz the radiation pattern is not symmetric and the phase varies a bit more . This is probably due to some inaccuracy on the manufacturing that became significant at 32 GHz. However, also at this higher frequency, if the phase is recentered around θ=-5 degrees the variation is relatively small (in order of 30 degrees).

4. CONCLUSION

In this paper, the Ultra Wide band version of the leaky lens antenna, the Pyramid antenna, is presented. The Pyramid antenna is characterized by unpaired performances over a two octaves bandwidth that can be briefly synthesized as follows:

1. Input impedance is weakly frequency dependent. The reflection coefficient can be maintained lower than -9 dB over the bandwidth.
2. The H-plane radiation pattern remains essentially frequency independent over a good part of the mentioned bandwidth.
3. The phase center is well defined and, observing inside the -10 dB beam width in the H-plane, the phase is substantially constant.

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