The Pyramid Antenna: a Directive and Ultra Wide Band Leaky Lens Antenna

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Introduction

Several fields could potentially benefit from the development of extremely broadband directive and non dispersive antennas. The ultra-wide band (UWB) technology, with the multi-band schemes in the frequency range 3.1-10.6 GHz regulated by the Federal Communication Commission (FCC), cries for transmission and reception system capable to guarantee very little distortion of the signals. In the field of electromagnetic compatibility (EMC) the exponential development of the Ku and Ka bands for telecommunication satellites and the growing interest for the 60 GHz Wireless Local Area Networks (WLAN) constitute a formidable reason to realize field sensors operating efficiently in broad and wide frequency ranges. Despite this needs, antennas tend to be the bottle neck of an EMC measuring system at high frequencies:

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 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 because the actual signal is transported via lossless fiber optics rather than with coaxial cables that are extremely lossy at frequencies higher than 10 GHz.

An ultra wide band (UWB) antenna with high directivity and low dispersion suited to be integrated with RX/TX circuits has been a a technological dream for decades. All existing broad-band antennas used to suffer from various kind of limitations, and one of the most successful examples, the Vivaldi antenna, typically trades off the bandwidth with variation of the phase center and high cross polarization levels.

In this contribution a novel ultra-wide band antenna is presented that overcomes these limitations resorting to a leaky wave radiation mechanism. At difference with standard leaky wave radiation the waves propagating at the interface between two homogenous infinite dielectrics radiate a beam which is largely frequency independent in the denser dielectric. The relevant Green's function was theoretically investigated in [1] and [2], while in [3], the first antenna prototypes using this mechanism were presented.

In this paper the design, manufacturing and measurement of the first Pyramid antenna is described. This antenna is suited for Coplanar wave-guide excitation which is the natural output of many integrated circuits. In particular, travelling wave electro optical Mach Zehnder (MZ) modulators, whose output is in CPW, can be easily integrated with the pyramid antenna and give birth to high frequency field sensor.

Antenna Description

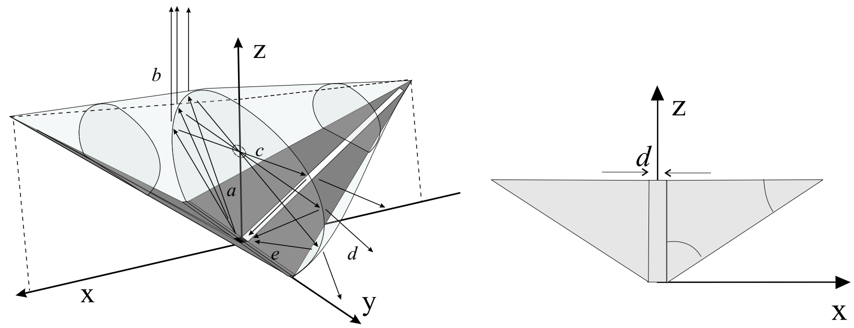
The UWB version of the leaky lens antenna concept is depicted in Fig. 1(a). The lens geometry is the composition of two leaky lens antennas [3]. The shape of each one of these dielectric lenses is obtained as union of an infinite set of cross section planes of truncated elliptical shape and decreasing dimension. Each of the ellipses contain 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 junction 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 d, on $x - y$ plane, see the side view in Fig. 1(b). 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 in the center of the CPW ground plane. The values of the angles α_t and γ are only functions of the lens dielectric constant: $\gamma = cos^{-1}\sqrt{\frac{\epsilon_{r1}+\epsilon_{r2}}{2\epsilon_{r2}}}$ and $\alpha = \frac{\pi}{2} - \gamma$.

As explained in [2] 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, though the structure is not planar, the rays are emanated from the slot (see a in Fig. 1) that constitutes the lower focus of the lens. After being launched, they can be (i) focused and transmitted at the first interface (b in Fig. 1, i.e. far field radiation) or (ii) reflected at the first interface (c in Fig. 1) and (iii) diffracted away from the antenna at the second interface (d in Fig. 1) or (iv) reflected at the second interface and refocused toward the slot (e in Fig. 1). 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. 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. 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).

Manufacturing and measurements

An antenna prototype was designed to operate in the frequency range 4 to 40 GHz. It was manufactured using ceramic material (TMM 3 from Rogers) for the lens, while the slot and CPW were etched from a copper layer deposited on the bottom face of the lens.



(a) (b)

Figure 1: a) Geometry of the Pyramid antenna with relevant rays in the central cross section, b) Side view.

In the design of the antenna aimed at operating over a decade bandwidth, it is not necessary to concentrate on second order details. One basic design aspect that cannot be neglected, and dominated the present design, is however the characteristic impedance of the CPW line, set to 50 Ohm, that centrally feeds the long radiating slot. From an impedance point of view, each one of the two arms can be considered infinitely extended, thus it's impedance could be associated to an *equivalent* characteristic impedance of a slot line. This implies that the input impedance of the long slot seen by the CPW can be approximated as the parallel of the two characteristic impedances, of the slot lines. A dedicated procedure was developed to evaluate the characteristic impedance of the slot that is not discussed here. The final result is in Fig. 2, that shows the complete lens antenna. The lens length, height and

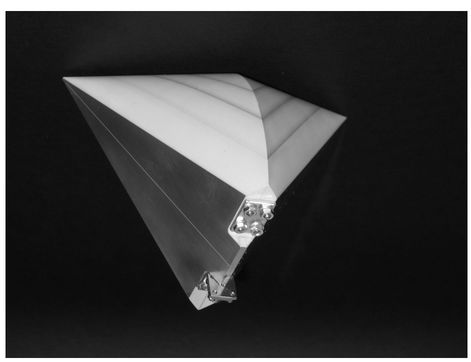


Figure 2: Final prototype.

width 18 cm x 10 cm x 7 cm respectively. The CPW line is as short as possible and is terminated at one end of the radiating slot with an SK coaxial connector. The simulated and measured reflection coefficients of the antenna when fed by a 50 Ohm transmission line are plotted in Fig. 3. It is below 9dB's for almost a decade of bandwidth. Radiation patterns and time domain measurements will be shown during the oral presentation.

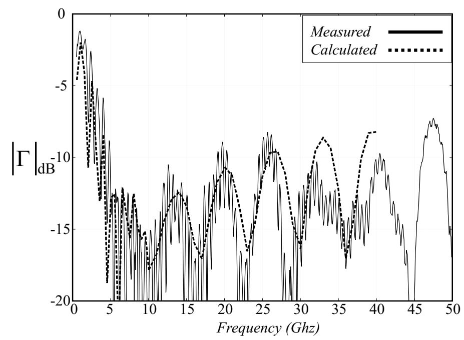


Figure 3: Reflection coefficient of the pyramid antenna.

Conclusion

In this work, we have designed a novel antenna topology, named the Pyramid antenna. It has unpaired bandwidth performances that can be briefly synthesized as follows:

1. Input impedance with limited frequency dependence. Reflection coefficients lower than -9dB's have been achieved over 1:8 bands.
2. Radiation pattern essentially frequency independent on the H-plane (on bands 1:10). In the E-plane the directivity grows as a result of the lens shaping.
3. With respect to all other broad band directive radiators the antenna's phase center is much more stable with frequency.

References

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