Enhanced Bow Tie Feeds for Dielectric Lens Antennas

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INTRODUCTION

Optically pumped THz systems exploit the interaction of electromagnetic fields at optical frequencies with doped Ga As substrates to generate electric currents with important components in the THz spectrum, [1]. Specifically, THz Time Domain Spectrometers (TDS) use femtosecond optical pulses to generate broad band electrons currents in a D.C. biased photoconductive switch [2], [3]. The currents, in turn, can be viewed as field sources, with efficiency which is dominated by the surrounding geometry they interact with: i.e. the antennas. These are typically required to operate over frequency bandwidths that exceed a decade, possibly inducing minimal dispersion in the radiated pulses. The state of the art in the field of tunable and pulsed THz sources is represented by wide band integrated antennas typically printed on dielectric slabs of thickness *E*, which in turn are glued to hemispherical dielectric lenses of radius *R*, Fig1 (a).

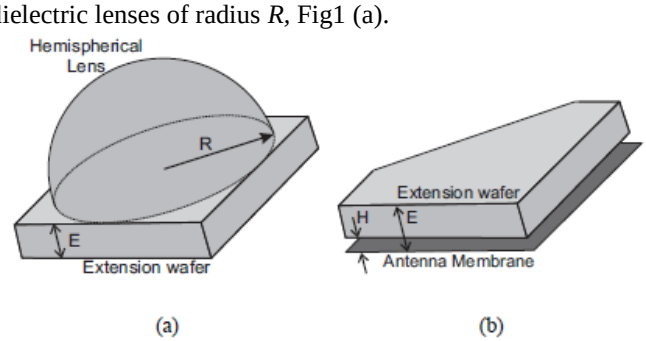


Fig. 1. Lens Geometry: (a) extended hemispherical lens with radius R and extension height E and (b) extension wafer including an air cavity H.

These antennas have been studied intensely. In this paper three linearly polarized feeds for such lenses, are discussed: the Auston switch, the bow tie and the long slot, Fig. 2. The Auston switch [3], is the one most widely used for THz TDS but to date the most performing linearly polarized and non dispersive feed for dielectric lenses is the bow tie. In fact, unexpectedly, bow-tie like antennas (i.e. long dipoles) have been shown to perform much better, [4], impedance wise than standard dipole switches. Despite representing the state of the art, the bow tie suffers from important reflections at the dielectric air interface which reduce its performance. A real solution could be the design of directive feeds which focus the energy toward the upper part of the lens. However, only narrow band structures were so far available as directive feeds for the dielectric lenses, [5].

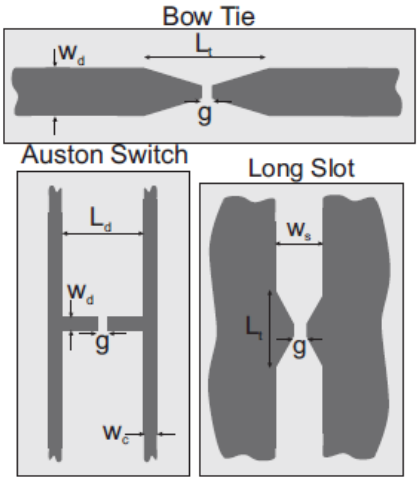


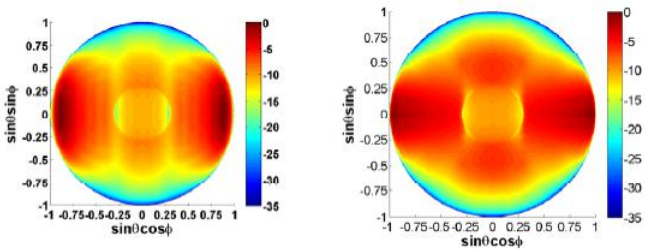
Fig. 2. Antenna Geometry: (a) Bow tie, (b) Auston switch, and (c) long slot.

The BW and dispersivity problem is essentially solved by the recently introduced, slot based as in Fig. 2c, leaky lens antenna [6], [7]. With respect to the standard bow tie and Auston switches the main difference is associated to the radiating antenna being printed on a membrane kept at a very small separation distance from the lens, Fig1. (b).

NUMERICAL RESULTS: BOW TIE AND LEAKY LENSES

The bow tie geometry considered here is essentially the one proposed in [4] with flaring only close to the feeding points. The explicit dimension are wd = 50µm and lt = 150 µm, with the central gap which is 5 µm x 5 µm for all antennas considered in this paper. The antennas are also connected to contact pads for d.c biasing. Accordingly the pads are lengthening the dipoles. The bow tie is in fact used in a frequency regime where it is extremely long in terms of the wavelength and radiates according to a leaky mechanism. As expected the matching as a function of the frequency is very smooth, and it does not show impedance resonances for frequencies above 100 GHz. The radiated patterns inside the dielectric are also quite frequency independent, as shown in Fig.3 where the field amplitude is plotted in elevation and azimuth. The bow tie radiates an important percentage of its power toward the lower angles of the lens, especially in the E plane. This creates high reflections at the dielectric air interface that are minimized resorting to low extension lengths, h. The counter indication of this strategy is that the

phase error cut off, implicit in using hemispherical lenses rather than the elliptical shape, occurs for lower frequencies.



(a) (b)

Fig. 3. Primary field amplitude of the Bow tie antenna at 500GHz (a) and 2THz (b).

The gain as a function of the frequency for the bow tie discussed in Fig.3and printed at the lower focus of an extended hemispherical lens of radius of R = 5mm and E = 0.31R is shown in Fig.4. Also reported is the comparison with a similar Auston switch printed inside the same lens. One should not for both the feeds there is a cut off frequency above which the antennas cannot be properly used due to the important phase error due to the reduced extension length E (it would be E=0.4 R for a synthesized ellipse) equivalent eccentricity. The patterns of the Auston switch, even if not reported are less symmetric and presenting high side lobes than those obtained via the bow tie.

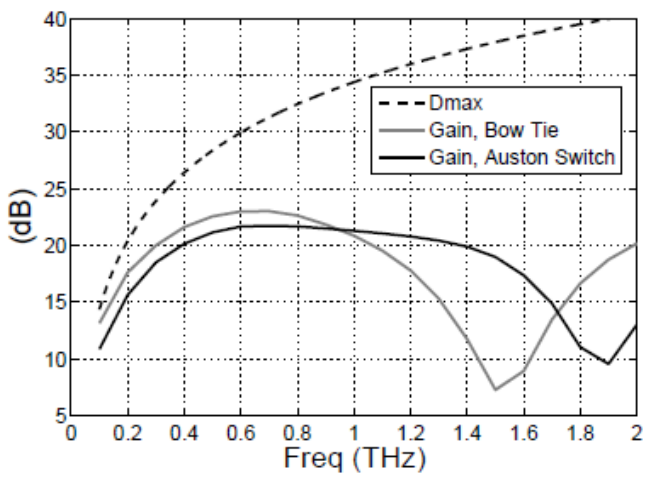
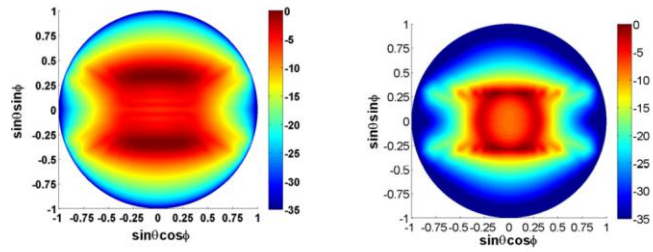


Fig. 4. Gain as a function of the frequency for a bthe bow tie discusses in section Primary field amplitude of the Bow tie antenna at 500GHz (a) and 2THz (b)

A higher extension length would have extended the usablefrequency range at the cost of higher reflection losses.

The last leaky lenses are the enhanced leaky lens slot antennas [6]- [7] which are completely planar and characterized by the separation air layer, h, between the Ga-As substrate and the lens. The inclusion of this air-layer guarantees that the radiation of the leaky mode happens, for dense dielectrics (εr > 10) for angles γ_{lw} in the order of 72°.

This value should be compared to 45o, which is the largest value that could be achieved, even for very large values of εr, when the antenna are printed directly on dense dielectric rather than on membranes. The slotted structure is shown in Fig. 2c). The characterizing geometrical parameters are the width w_s = 25μm the separation layer, h=12.5μm, and the tapering of length l_t = 150μm toward the feed point, where the slot is w_f wide. The slot extends below the entire lens.
The central gap is 5μmx5μm for all antennas considered The fields radiated inside the dielectric by the slot are quite frequency independent, as shown in Fig.5, and focused in the central portion of the lens. The fields peaked around the critical angle of 18° from the normal (72° from the ground plane). The fields are also almost rotationally symmetric. Since the central portion of the lens is the most efficient one, these lenses are also characterized by very clean secondary beams.



(a) (b)

Fig. 5. Primary field of the enhanced leaky wave slot antenna at 500GHz (a) and 2THz (b).

The gain as a function of the frequency for the slot fed leaky lens discussed in Fig.5 and printed at the lower focus of an extended hemispherical lens of radius of R = 5mm and E = 0.31R is shown in Fig.6. Also reported is the comparison with a similar Bow tie Bow tie (w_d = 50μm,l_t = 150μm). printed on the same small membrane.

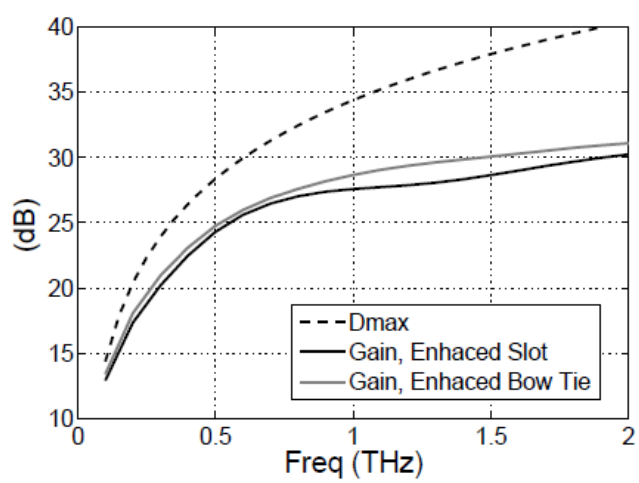


Fig. 6. Gain as a function of the frequency for slot or bow tie fed leaky lens

Thanks to the fact that extension length is kept small, E = 0.31R, the lens gain is slowly varying with frequency, with an overall gain that increases by 6 dB on the band that spans from 500 GHz to 2 THz. The standard expectation for a fully excited aperture would imply a gain grow of 12 dB in the same frequency span. The front to back ratio is the only limit to the higher frequency usability of these antennas. In fact as the frequency increases the separation h becomes significant in terms of the wavelength and the leaky wave mechanism can loose its dominant role to direct space wave radiation. As this happens a larger portion of the energy radiated by the slot is not coupled to the lens. However, for small values of h the front to back ratio loss grows only linearly with frequency without any real cut off frequency.

CONCLUSIONS

In this paper, by providing a fair comparison of the performances of three feed types, the enhanced leaky lens antennas, fed by slots or by bow ties are shown to provide significantly superior performances in terms of power x bandwidth with respect to the state of the art in non dispersive lens feeds. The enhancement corresponds to printing them on a thin membrane kept at close distance from the dielectric lenses. Even if not reported also the pattern quality is significantly better. The advantages are particularly important when the antenna is to be used as feed of a focusing reflector. However significantly improved, bow ties will still suffer from some level of beam asymmetry in the two planes which are not there in the case of the slot fed leaky lenses.

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