Miniature Elliptical Substrate Lenses for Millimeter-Wave Imaging

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***Abstract*—The use of an array of miniaturized elliptical substrate lenses or mini-lenses, combined with an array of printed antennas, is proposed for plasma imaging applications. Compared with its predecessor, the large hyper hemispherical lens, the new configuration demonstrates reduced sidelobe levels, minimal off-axis aberrations, increased RF bandwidth, and enhanced local oscillator coupling with substrate side LO illumination.**

I. Introduction And Background

ELECTRON cyclotron emission (ECE) imaging (ECEI) and microwave imaging reflectometry (MIR) are plasma visualization techniques employed to study the dynamics of electron temperature T_e and electron density n_e fluctuations, respectively. ECEI collects broad bandwidth millimeter wave ECE radiation and uses large aperture optics to image it onto a 1-D planar mixer array to form 2-D T_e fluctuation images [1]. MIR is a radar technique in which large aperture optics at the plasma edge illuminate an extended portion of the plasma cutoff layer with low power millimeter-waves, and then collect as much of the scattered wavefront as possible and optically focus an image of the cutoff surface onto a similar 1-D array [2]. ECEI and MIR systems require high performance optical systems to obtain the radiation intensity and phase front, respectively.

II. Hyper hemispherical lens Or Elliptical lens

Currently [1][2], the ECEI and MIR mixer arrays employ dual dipole antennas (16 channels) together with a large (120 mm diameter) hyper-hemispherical substrate lens (Fig. 1, left) shared by all antenna elements. The usable RF bandwidth is limited by the constrains the common substrate lens imposes on feeding local oscillator (LO) power to the off-axis elements through the substrate lens, thereby necessitating the use of air side LO pumping. Because of limited amounts of LO power available, antennas resonant with the air side LO are employed rather than the substrate side RF. The antenna geometry is then fine-tuned to provide "clean" RF antenna patterns over the range of frequencies for which the LO power could be efficiently coupled to the array.

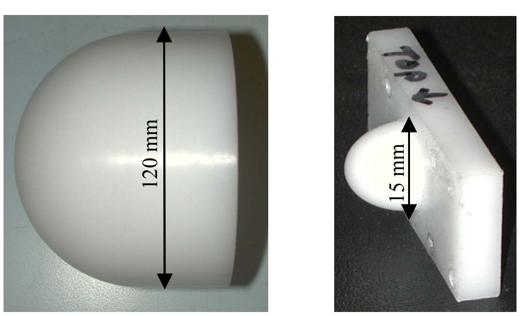

Fig. 1: Photographs of the large hyper-hemispherical substrate lens (left) and miniature elliptical substrate lens (right).

The new imaging array concept involves the use of an array of miniature elliptical lenses or mini-lenses (see Fig. 1, right). The elliptical lens is designed to refract rays originating at its focus so that they emerge parallel to each other [3]. The elliptical lens geometry depends upon two parameters: eccentricity determined by the material refraction index n and the diameter (minor axis) chosen arbitrarily [4]. For plasma imaging applications, high density polyethylene (HDPE) has been used with refraction index n=1.53. The diameter of the ellipse is 15 mm. The new imaging array has been fabricated with a staggered arrangement for cross correlation studies (Fig. 2). Each dual dipole antenna element (see Fig. 3) occupies one single mini lens.

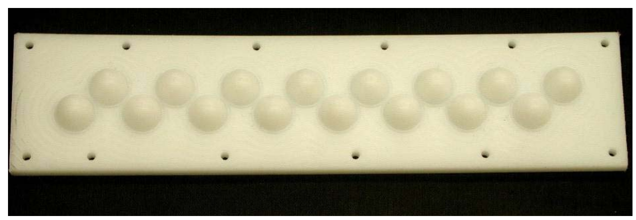

Fig. 2: The new mini lens array with staggered arrangement (16 channels) for 2-D plasma visualization.

Taking advantages of the excellent optical properties [3], there is no need to consider the difficulty of feeding LO to the off-axis elements, since every element is positioned in the center of each mini lens in this configuration. Two important improvements have been made arising from this configuration: enhanced antenna pattern and front side LO illumination.

III. Enhanced Antenna Pattern

For the hyper hemispherical lens, the LO couples to the detector array from the air side because of limited LO power; consequently, as mentioned above, the antenna geometry is mainly determined by the LO coupling, not the RF; therfore, the RF (substrate) side antenna pattern is not optimized. The result is that the antenna geometry is over sized compared to the optimum geometry from RF considerations. The new dual dipole antenna is much smaller than previous ones (Fig. 3)

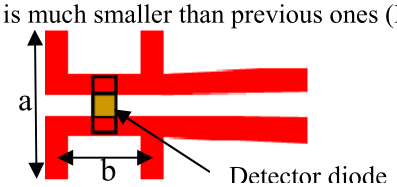

Fig. 3: The reduced sized dual dipole antenna with a dimension a=1.27 mm, b=0.71 mm. A detector diode is across the feeding lines. For the previous oversized antenna, a=b=2.44 mm,

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Since we are interested in ECE radiation roughly from 90 GHz to 140 GHz, the patterns were measured from 70 GHz to 165 GHz using W-band and D-band Backward Wave Oscillators (BWOs). The BWO signal was modulated by a mechanical chopper, and the output from the dual dipole antenna detector was fed to a lock-in amplifier. The received signal (voltage) was measured by a digital multimeter. A significantly improved antenna pattern (Fig. 4) has been observed, compared with the large hyper hemispherical lens antenna pattern (Fig. 5)

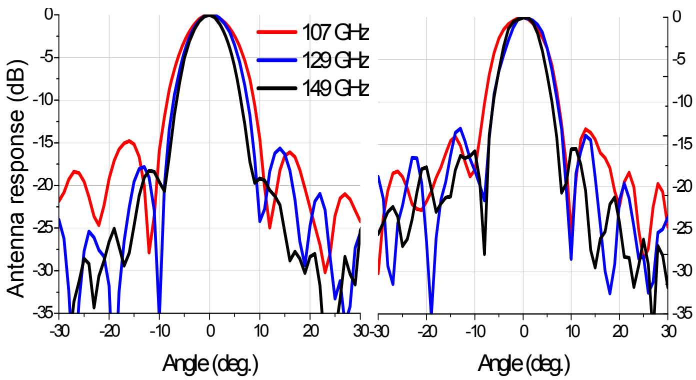

Fig. 4: Measured E- (left) and H-plane (right) normalized patterns of a mini lens-based dual dipole antenna as a function of frequency.

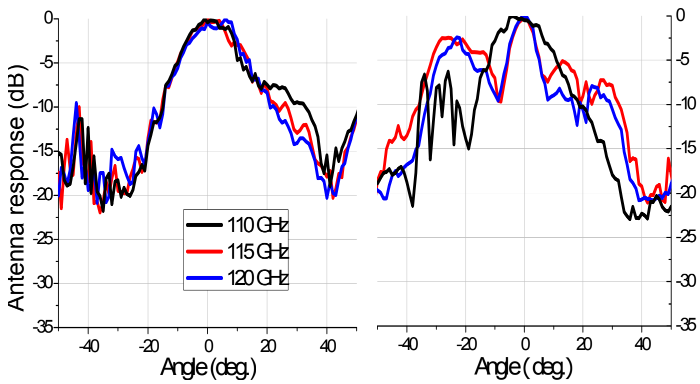

Fig. 5: Measured E- (left) and H-plane (right) normalized patterns of the present ECEI antenna (employed on the TEXTOR plasma device) as a function of frequency.

IV. FRONT SIDE LO ILLUMINATION

In addition to providing significantly improved antenna patterns, the configuration is also ideal for the use of front-side LO pumping in that each mini-lens is already optimized for coupling a collimated LO beam onto its dedicated antenna. For verification purposes, the antenna sensitivities for both substrate side and air side illumination have been measured over the same frequency range from 66.7 GHz to 165 GHz. (see Fig. 6). The sensitivities on the substrate side are about 10 dB stronger than those on the air side, which also strongly motivates the application of the LO power from the front side of the substrate lens. The front side LO design employ two optical lenses (HDPE) and one dichroic plate to shape the LO power to a long (E-plane) and narrow (H-plane) region which covers the entire area of the mini lens array (see Fig. 7).

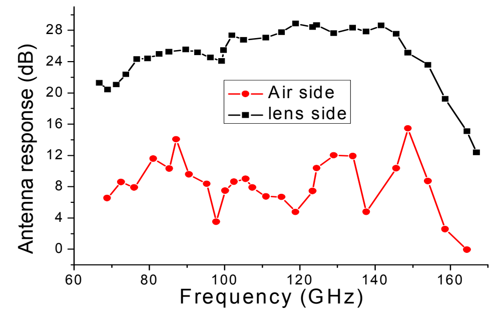

Fig. 6: Measured dual dipole antenna sensitivities at substrate side and air side as a function of frequency.

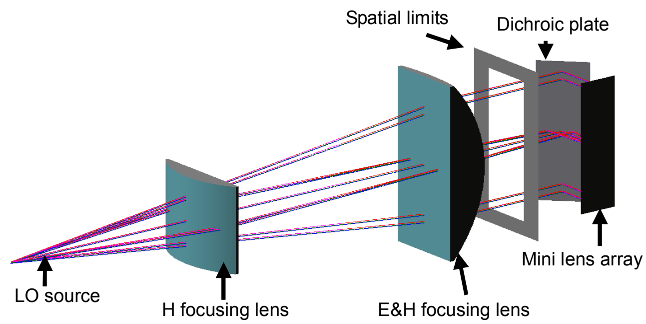

Fig. 7: Conceptual front side LO illumination configuration, two focusing lenses, and a dichroic plate (works as a beam splitter to separate from RF) are employed to shape the LO power onto the mini lens array.

The dichroic plate has two functions: as a beam splitter to separate the LO from RF signal and as a high pass filter for single side band LO/RF mixing. Limited by the small tilt angle of the dichroic plate as well as other spatial limits, such as finite packaging width, the real design needs an additional mirror to make it function properly. Testing work for the front side LO illumination is underway. High RF/LO mixing efficiency and increased ECEI and MIR spatial resolution are expected from the application of new miniature elliptical substrate lens array.

V. ACKNOWLEDGEMENT

This work was supported in part by the U.S. Department of Energy under Grants DE-FG02-99ER54518, DE-FG02-99ER54531 and DE-AC02-76-CHO-307.

REFERENCES

[1] H. Park et al., *Rev. Sci. Instrum.* **75**, 3787 (2004).

[2] T. Munsat, E. Mazzucato, H. Park, B.H. Deng, C.W. Domier, N.C. Luhmann, Jr., J. Wang, Z.G. Xia, A.J.H. Donné, M. van de Pol, *Rev. Sci. Instrum.* **74**, 1426 (2003).

[3] E. Hecht, *Optics*, 2nd Edition, Reading, MA: Addison-Wesley, 129-131 (1987).

[4] D. F. Filipovic, S. S. Gearhart, G. M. Rebeiz *Transactions on Microwave Theory and Techniques*, **41**, No. 10 (1993)