

PHASE IMAGING SYSTEMS FOR MEASUREMENT OF PLASMA DENSITY CONTOURS

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I. Introduction

During recent years, there has been considerable interest in obtaining spatially localized time resolved density measurements in fusion plasmas. However, the study of such phenomena requires many channels of information on a scale much finer than available with current discrete chordal view multichannel interferometers. These problems can be overcome by imaging an expanded probe beam occupying the entire plasma port crosssection onto a linear detector array^[1], thereby significantly reducing the number of optical components and hence the cost and complexity of the system compared with a comparable discrete chord multichannel interferometer. Other more fundamental advantages of the imaging technique include compensation for phase errors due to plasma refraction, whilst the diffraction limited system resolution (typically $\approx 1\text{cm}$ for FIR probe wavelengths) allows the use of many detector channels for high spatial sampling rates, and hence accurate reconstruction of the density profiles.

II. Phase Imaging Systems

A. Detectors

The heart of the imaging system consists of a monolithic integrated microbolometer array which is comprised of a line of bow-tie antennas with micron sized bismuth microbolometer detectors^[2-5] located at their apex printed on a quartz-substrate. The antennas are separated by approximately half a dielectric wavelength in the substrate in order to ensure diffraction limited imaging performance. To eliminate the excitation of substrate modes which degrade the antenna efficiency as well as the imaging properties, a hyperhemispherical substrate lens is employed with the radiation coupled in through the rear surface of the substrate as shown in Fig. 1.

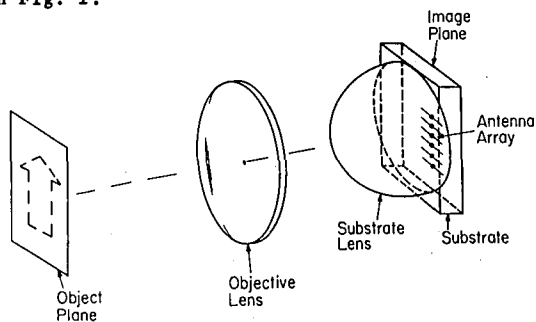


Figure 1. Optical elements used with the detector array.

B. Probe Sources

The development of large detector arrays has placed a burden on source technology since the increased number of channels results in a need for higher source power. The increased channel number, coupled with the NEP and responsivity of the microbolometer detector arrays and the tokamak noise background leads to probe power requirements of $\approx 0.1\text{--}1\text{W}$. On a small tokamak such as Microtor we have been able to operate at 1 mm so that we could avail ourselves of the relatively high output power of carcinotrons (0.6 W). However, for a large device such as TEXT in order to minimize refractive bending, a wavelength of $\sim 400\text{ }\mu\text{m}$ is required thereby necessitating the use of a CO_2 pumped FIR laser which produces an output power on the $393\text{ }\mu\text{m}$ HCOOH line of $\sim 140\text{ mW}$. For the Microtor system an IF beat frequency of $\sim 80\text{ kHz}$ is produced using a rotating grating, whilst the TEXT experiment utilizes a twin FIR laser system operating at an IF of $\sim 750\text{ kHz}$ with a measured short term jitter of $\pm 10\text{ kHz}$.

C. Optical Arrangement

In order to illuminate the entire plasma crosssection, the imaging system must employ beam expansion optics. In the Microtor system (Fig. 2) this is accomplished using cylindrical lenses. However, the shorter operating wavelength and increased component size for TEXT preclude the use of large refractive optics. In this case a set of large off-axis parabolic cylinder mirrors are employed for the beam expansion and reduction. The experimental configuration at TEXT is shown schematically in Fig. 3.

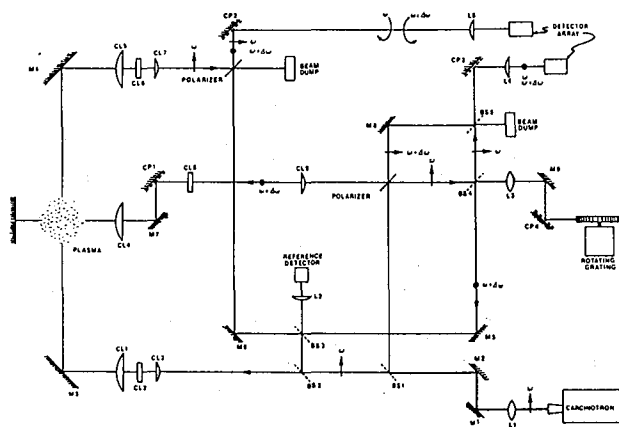


Figure 2. 2-D phase imaging system installed on Microtor Tokamak.

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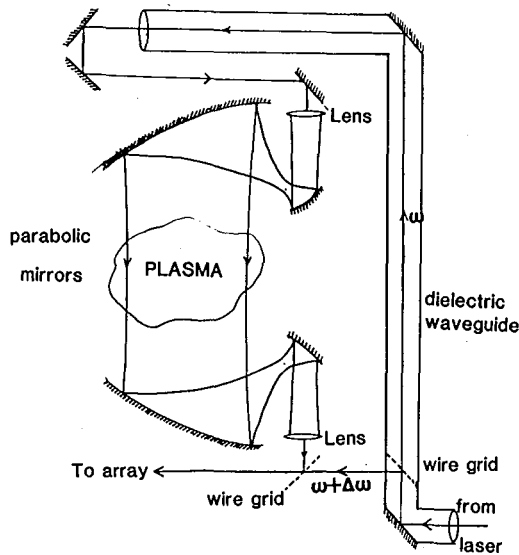


Figure 3. Text phase imaging system showing beam expansion mirror.

Having previously demonstrated the phase imaging capability of the Microtor system in one-dimension (vertical plane), the system has now been reconfigured to give 40 channels of phase information in two dimensions.

The performance of the horizontal arm is also strongly affected by refraction (due to the double pass of the plasma), and the lens design has been optimized using a ray tracing code which simulates the effects of plasma refraction on the imaging system behaviour (Fig. 4).

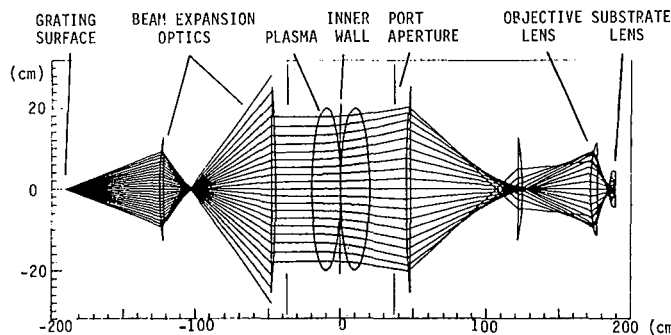


Figure 4. Results of ray-tracing code showing effects of refraction on probe beam path assumed parabolic density profile with $n_0 = 3 \times 10^{19} \text{ cm}^{-3}$. The two axes are not equi-scaled.

A notable feature of the optical system is its use of polarizing optics to separate the incident and reflected beams from the grating and from the vessel inner wall. The reflecting circular polarizers CP1 and CP4 are adjusted to make the return beam polarization orthogonal to the incident beam and hence be transmitted or reflected respectively from the polarizer P1.

III. Results

Results showing both amplitude and phase imaging of test objects using the experimental arrangement of Fig. 2 are presented in Fig 6. The image shape and width are consistent with the expected system magnification and resolution. First phase imaging data obtained on the Microtor plasma is shown in Fig. 7 which displays the 20 channel line density profile obtained in the vertical view. Note that the profile is reasonably centered in the vacuum vessel and appears nearly parabolic.

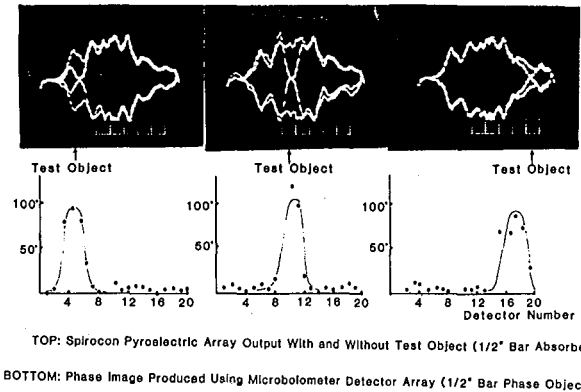


Figure 5. Amplitude and Phase images of test objects.

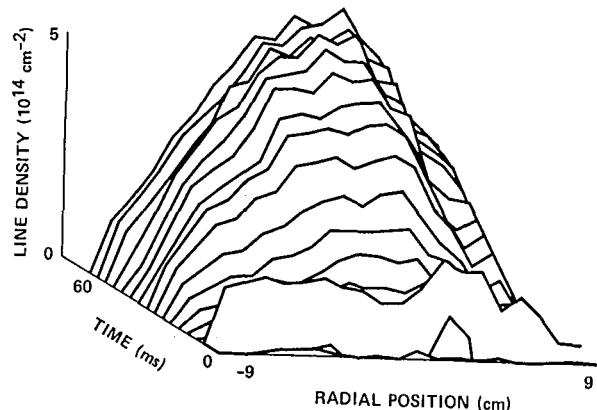


Figure 6. 20-channel line-density profile for microtor tokamak.

IV. References

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