INTERFEROMETRIC FIR PHASE IMAGING OF A TOKAMAK PLASMA

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Abstract

Multichannel phase imaging of dielectric objects has been demonstrated in the laboratory using a microbolometer detector array and 400 GHz carcinotron radiation cource. The application of this imaging system to perform single shot measurements of electron density profiles in a tokamak plasma is described. The primary advantages are increased spatial resolution together with a much simpler optical system.

Experimental Arrangement

A schematic of the optical system is shown in Fig. 1. This is basically a heterodyned Mach-Zehnder interferometer which uses a rotating grating to Doppler shift the reference beam relative to the probe beam by 90 kHz. A pair of polyethylene cylindrical lenses is used to expand the probe beam in one dimension so that the entire plasma crosssection is illuminated. The ports on UCLA Microtor are roughly 3 cm by 20 cm in size and allow a clear view across the plasma. The primary effect of the plasma on the probe beam is to alter the spatial phase distribution which can then be imaged onto a detector array. This is accomplished in practice by first using a pair of cylindrical lenses to reduce the size of the probe beam to match the reference beam crosssection. An f/1 aspheric lens produces an image on the detector array.

The detector array [1] consists of bismuth microbolometers with bowtie antenna structures which are deposited on a quartz substrate and are separated by 310 μm. The radiation is coupled into the detectors through the quartz to take advantage of the increased antenna gain compared to the gain obtained by coupling on the air side. Generation of substrate modes due to internal reflections is substantially reduced by placing a hyperhemispherical lens on the substrate. This forms an aplanatic optical system with the array at the image plane.

Limitations and Results

In practice there are limitations to the resolution of such a system. The pass band of the optics is limited by apertures of finite size. There will be a cutoff of spatial frequencies at [2]

$$f_c = \frac{n}{2\lambda f^{\#}}$$

where n is the index of refraction of the medium in which the image is formed, λ is the wavelength, $f^{\#}$ is the f number of the imaging optics. The image is formed in quartz ($n \approx 2$), $\lambda = .8$ mm, and $f^{\#} = M$ where M is the magnification produced by the cylindrical lens pair. For our designed tokamak system we find $f_c^{-1} = .6$ cm which means that we will be undersampling a 20 -cm diameter plasma with a 20 channel system.

The other limitation is imposed by the presence of aberrations. These will cause phase distortions of the frequency response of the optical system within the pass band. While in theory aberrations can be corrected, we have not yet investigated the design of the corrected lenses which could become quite complicated.

Test dielectrics have been imaged in a laboratory experiment. Figure 2 shows the image of a polyethylene cylindrical lens compared with the theoretically predicted phase change. This is an object with low spatial frequency and simulates the expected plasma profile. Figure 3 shows the image of a teflon bar as it is moved across the field of view. This has a phase pulse distribution which contains frequency components above the cutoff frequency so we expect some smoothing of the image. Note also that the edge of the bar appears much sharper when it is near the optical axis than when it is towards the field edge. This is probably due to aberrations. The object field size for both Figs. 2 and 3 is 9 cm.

A 14-channel interferometer is presently being installed on UCLA Microtor. Results from this system will be presented and will be compared to profiles obtained with a single-channel interferometer that is scanned from shot to shot.

References

[1] D.P. Neikirk, D.B. Rutledge, M.S. Muha, H. Park, C.X. Yu, Appl. Phys. Lett. 40, 203 (1982).
[2] D.B. Rutledge, D.P. Neikirk, D.P. Kasilingam, "Integrated-Circuits Antennas" in Vol. 10 of Infrared and Millimeter Waves, K.J. Button, ed. Academic Press.

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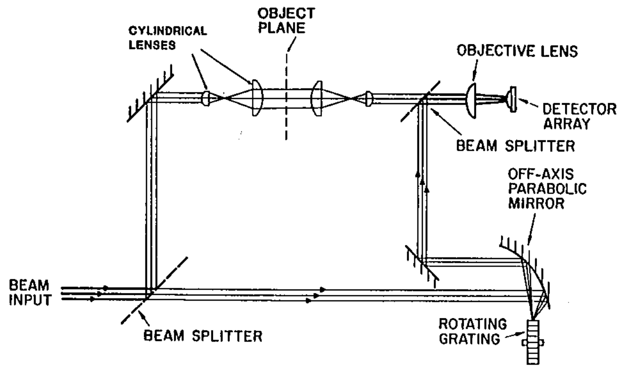

Figure 1 Schematic of the optical system used to phase image dielectric objects in the laboratory. The cylindrical lenses produce an elliptical crosssection beam in the object plane

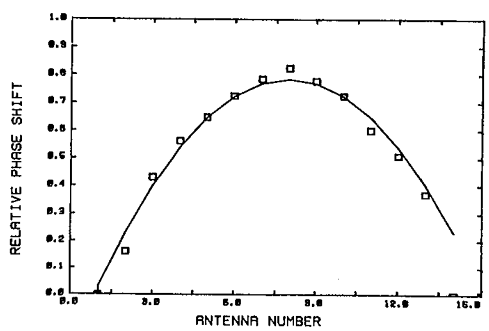

Figure 2 Phase image of a polyethylene cylindrical lens using the microbolometer array. The solid curve is the theoretically predicted phase profile.

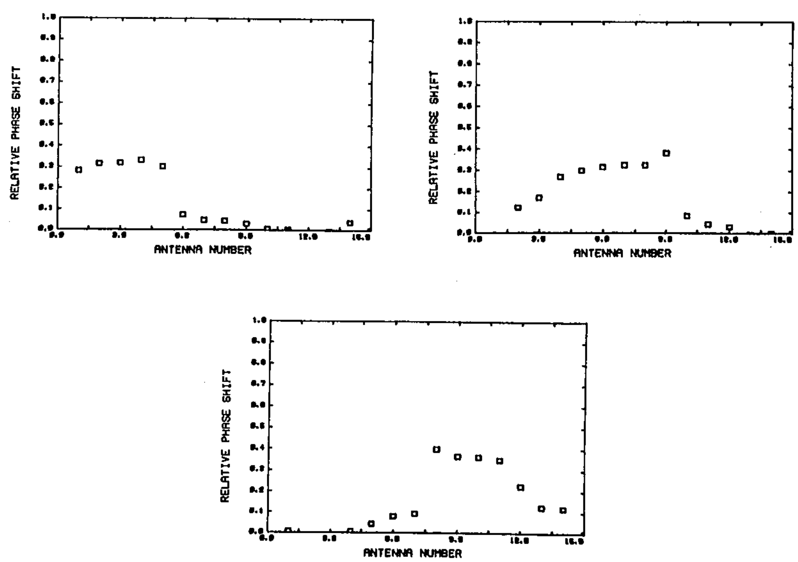

Figure 3 Phase image of a teflon bar using the microbolometer array. The three images are for different object locations as the bar is moved across the field of view. Note the loss of resolution near the edge of the field of viev-

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