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CHARACTERISTICS OF THE TEXTOR MICROWAVE IMAGING REFLECTOMETRY SYSTEM

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1. Introduction

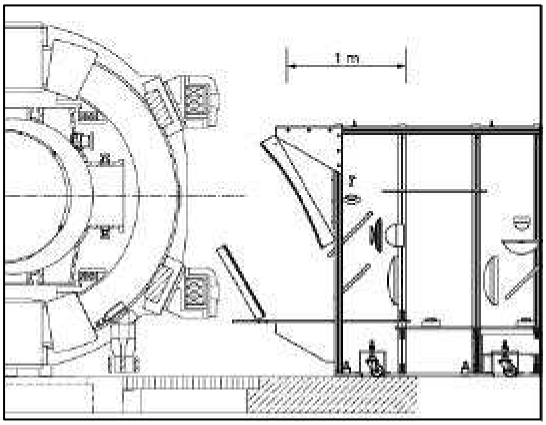
The problem of anomalous transport in magnetized plasmas and its relationship to small amplitude microturbulence continues to be of critical importance to a basic physics understanding. Reflectometry techniques have been a dominant diagnostic tool for density fluctuation measurement due to the excellent localization and sensitivity. Unfortunately, the 1-D geometrical optics approximation of the conventional reflectometry breaks down in the case of multidimensional turbulent fluctuations, which is precisely the case of interest for magnetic fusion plasma diagnostics where there are large radial and poloidal variations. The need for Microwave Imaging Reflectometry (MIR) has been well documented through detailed reflectometry studies, which have revealed the crucial need for reflectometric imaging (together with the failure of standard fluctuation reflectometry)[1,2].

An innovative fluctuation diagnostic, Microwave Imaging Reflectometry (MIR), is under development for TEXTOR[3]. This system has the potential of ameliorating the interpretation problem of reflectometry measurements of density fluctuations, particularly in the plasma core, as observed by 1-D reflectometer measurements from TFTR. Characterization tests illustrate both the difficulties of interpreting conventional reflectometry data (and the possibility of erroneous conclusions regarding core fluctuations) as well as the edge and the solutions offered by the MIR approach. Most importantly, the preliminary test results confirm the design specification of the TEXTOR MIR system.

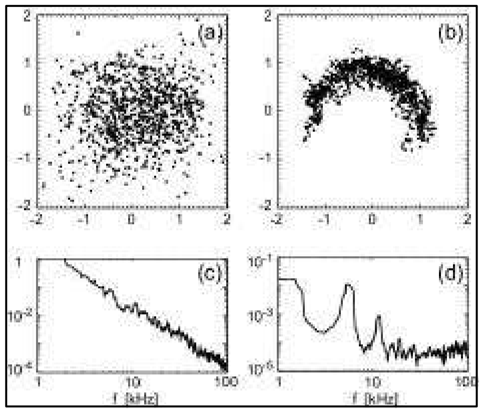
2. TEXTOR MIR system

Shown in Fig. 1a is a schematic diagram outlining the experimental realization of reflectometric imaging combined together with an Electron Cyclotron Emission Imaging (ECEI) system on TEXTOR. The primary focusing optical set is comprised of two large cylindrical mirrors (poloidal and toroidal), which tailor the probing beam wavefront to the 2-D cutoff surface. The reflected radiation passes back through the same imaging optics as the illuminating beam, with additional optics utilized to image the reflecting layer onto the detector array. On the detection side, sixteen mixers of the imaging array cover an *~ 15 cm* poloidal region of the cutoff surface with a spatial resolution of *~1 cm*, which will provide a poloidal wavenumber resolution of $0.4 < k < 3\ cm^{-1}$. The imaging array yields output signals whose frequency is that of the difference frequency between the probing and local oscillator sources. A quadrature detection system yields the fluctuating phase and amplitude signals on each array element.

Proof-of-principle experiments employing the systems shown in Fig. 1 have been performed on the TEXTOR-94 tokamak using fixed-frequency versions of both the ECE and reflectometer subsystems, confirming the feasibility of the imaging scheme. One of the most significant results from the prototype MIR system is the demonstration of the virtual cutoff surface as shown in Fig. 1B. In this experiment, both the probing frequency and the focal plane of the optics were held fixed, and the electron density was ramped over the course of the shot to bring the cutoff surface through and beyond the focal plane of the optics. Figure 1B shows the complex signal recorded over two *~3 ms* duration time windows as the cutoff surface moves outward through and beyond the optical focal plane. Both the characteristic crescent-shaped phase modulation when the cutoff is in-focus and the fill-in of the complex plot when the cutoff is out of focus are clearly identifiable.



(A)



(B)

Figure 1. (A) Layout of the combined ECEI/MIR system, showing the TEXTOR cross-section, the optical components, and the diagnostic support framework. (B) Test results from prototype system; demonstrates both "out-of focus(a,c) and in-focus(b,d)" by changing plasma density. Also power spectra are shown for each case.

Currently, a combined ECEI and MIR system is under development for the TEXTOR tokamak and will be installed this summer to prepare experimental program starting in October 2002.

3. Characteristics of TEXTOR MIR system

Simultaneously with the installation of ECEI/MIR system on TEXTOR, we have initiated a systematic characterization of the reflectometer, using corrugated reflecting targets of known shape to simulate the fluctuating plasma reflection layer. This approach was chosen to augment the plasma measurements due to the unavoidable complexity of any new plasma data; calibration of any new instrument is made much more reliable by first employing known reference targets. In this process, both the MIR and a conventional 1-D reflectometer system were used to reconstruct the phase of the target surface. As a reference, the surface was independently measured using a visible-laser interferometer (Leica "Laser Tracker") that has a resolution of ~ *10 micron*. Clearly from the plot in Fig. 2a, the MIR system accurately reproduces the target fluctuations (at a distance of over *200 cm*) while the 1-D conventional reflectometer data (Fig. 2b) becomes completely distorted, even at a distance of *50 cm*. The poloidal wavenumber of the target was $1.25\ cm^{-1}$, and the equivalent density fluctuation level (for typical TEXTOR parameters) was *~1%*.

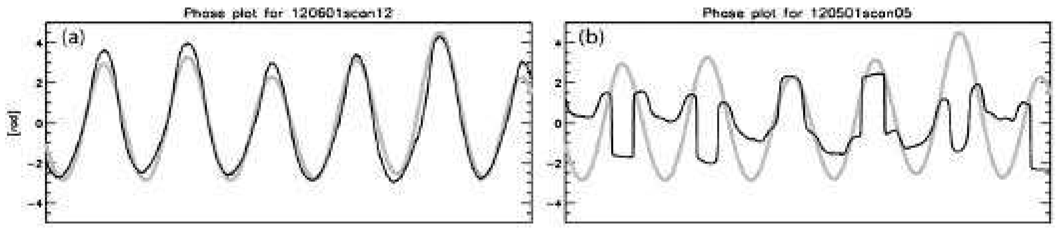


Figure 2. Laboratory test of MIR using a corrugated target mirror. Phase reconstruction of known target surface using (a) MIR imaging system, located 235 cm from reflection surface, and (b) conventional reflectometry system, located 50 cm from reflection surface. The light gray curve represents the actual surface, as measured by a separate visible-laser interferometer.

This simple experiment makes abundantly clear both the difficulties of interpreting conventional reflectometry data and the solutions offered by MIR techniques.

In order to quantify the degree to which the reflectometer measurements accurately reproduce the shape of the reference surface, the cross-correlation was calculated between the power spectra of the reflectometer and reference measurements over a wide range of *d*, the distance between the instrument and the target surface. These data, plotted for both the 1-d and MIR systems, are shown in Fig. 3. For the 1-d case, the correlation is nearly unity for *d~10 cm*, and falls as the distance is increased to *30 cm* or more.

For the MIR system, there is near-unity correlation between the signal and reference curves everywhere within *+-10 cm* of the focal distance. The strong correlation over this *20 cm* range represents the distance over which multi-radial (multi-frequency) data could be collected simultaneously with a fixed set of imaging optics. Importantly, these data are taken with the instrument at a distance of over *200 cm* from the reflecting surface, in

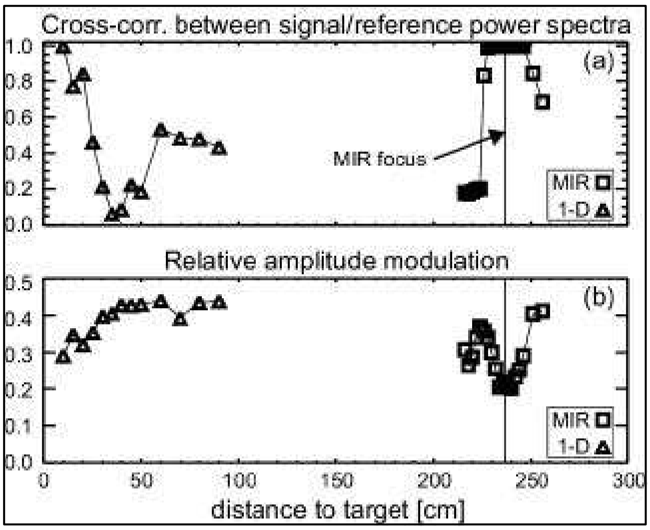


Figure 3. Cross-correlation between reflectometer phase and reference phase (a), and signal amplitude modulation (b). The MIR focal plane is indicated by the vertical line at a distance of 237 cm from the target. The region more than 50 cm away from the cutoff layer (target position) is a typical distance of 1-D system in standard tokamaks.

exactly the configuration used for TEXTOR measurements.

The critical test results of the TEXTOR MIR system have demonstrated that imaging reflectometry is the inevitable choice for studying core density fluctuations in toroidal devices where the distance between the detection system and cutoff layer is more than *~50 cm* in general. Recent progress in detector array research has allowed us to employ dual dipole antennas which have a much cleaner and more symmetric antenna pattern, compared to the slot-bowtie antennas which were used in previous experiment. The optical system of the imaging system will be further characterized with an actual detection array to complete the test of the MIR system on TEXTOR.

4. References

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