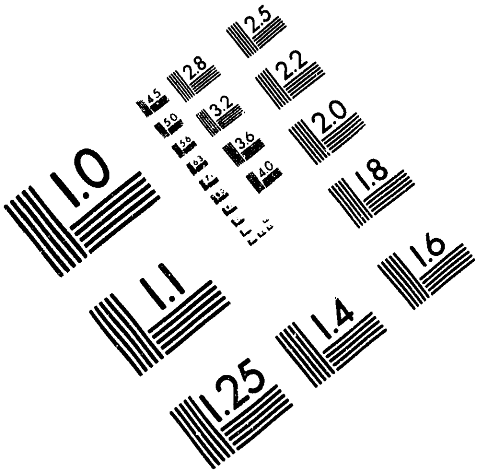

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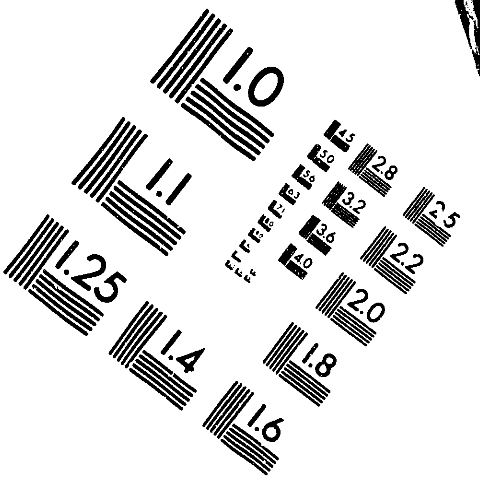

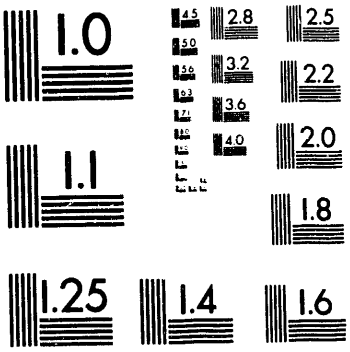

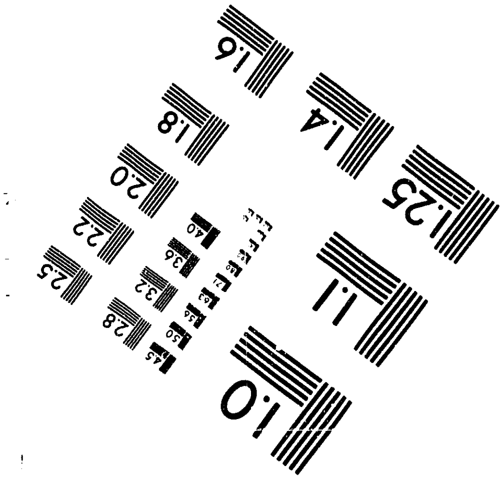

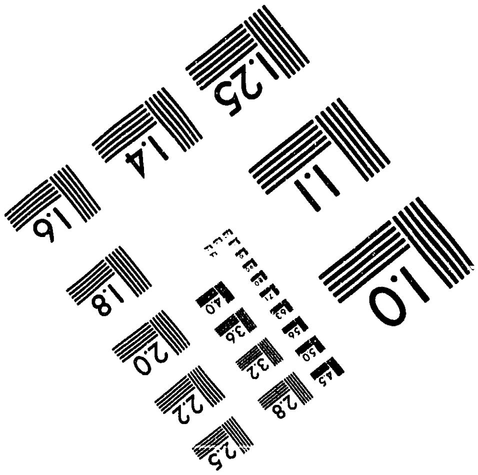

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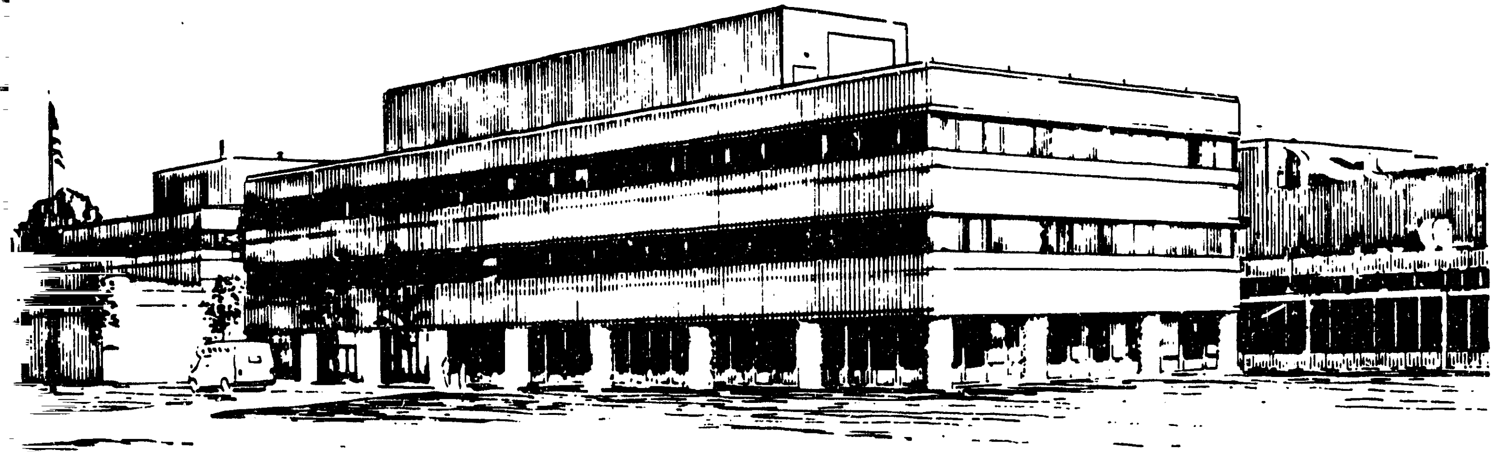
BY

J.B. WILGEN, G.R. HANSON, T.S. BIGELOW, ET AL.

JUNE, 1993

PPPL PRINCETON PLASMA PHYSICS LABORATORY



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MICROWAVE REFLECTOMETRY FOR ICRF COUPLING STUDIES ON TFTR

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ABSTRACT

A dual-frequency differential-phase reflectometer has been developed for use in ICRF power coupling studies on TFTR. This system has been optimized for measurements of the electron density profile in the edge-gradient region, where density fluctuations are large. Initial proof-of-principle measurements demonstrate that this is an effective way to measure the electron density profile in the plasma-edge region. A new reflectometer launcher is presently being installed on the center axis of the bay-K ICRF antenna on TFTR, along with the associated waveguide transmission line. This will allow direct measurement of the edge-density profile within the high-power-density environment of the ICRF antenna where density profile modification might be expected.

INTRODUCTION

The coupling of ICRF power to the plasma is sensitive to details of the density profile in the plasma edge region, and the high power density ICRF environment can potentially alter the edge-density profile, at least locally in the immediate vicinity of the ICRF antenna. Theoretical ICRF antenna coupling calculations show that density profile changes immediately in front of the ICRF antenna can result in changes in the antenna loading by a factor of 2 to 3. Similar loading changes have been observed experimentally during ICRF heating. Reflectometer measurements of the edge-density profile can be used to correlate changes in antenna loading with shifts of the fast wave cutoff density. Consequently, there is significant interest in obtaining detailed measurements of the shape of the edge-density profile, and it is particularly important that the measurement be performed in the ICRF antenna environment.

DUAL-FREQUENCY DIFFERENTIAL-PHASE REFLECTOMETER

A dual-frequency differential-phase reflectometer has been developed for use in ICRF power coupling studies on TFTR[1]. This system has been optimized for measurements of the electron density profile in the edge-gradient region where density fluctuations are large. A differential-phase measurement was chosen because the multiplicity of fringes is thereby greatly reduced, and phase fluctuations arising from density fluctuations in the plasma are also significantly reduced. Both of these attributes are essential for reliable phase-tracking of multiple-fringe phase data.

A block diagram of the reflectometer as configured for a proof-of-principle measurement on TFTR is shown in Fig. 1. To provide the capability to measure the edge-density profile in the range between 1.0×10^{12} and 3.0×10^{13} cm^{-3} in high field (4.5–4.9 T) IRCF-heated TFTR plasmas, the frequency range of 91–117 GHz was chosen, corresponding to extraordinary mode polarization. Starting with a swept frequency source at low frequency, (8.0–12.4 GHz), upconversion and frequency multiplication

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(doubler and tripler) are used to provide the frequencies of interest. In this way, the frequencies of two probing signals are simultaneously swept from 91 to 117 GHz while maintaining a fixed frequency separation of 250 MHz. This frequency spacing determines the radial separation of the dual cutoff layers in the plasma, which should be small in comparison with the radial correlation length of the plasma density fluctuations if a reduction in the differential-phase fluctuation level is to be effected. Amplitude fading in the reflected signal amplitude is removed through the use of constant-phase limiting amplifiers. Heterodyne detection is used to measure the differential phase delay between the two signals, which can then be used to reconstruct the shape of the density profile.

INITIAL RESULTS ON TFTR

To facilitate testing of this reflectometer in a realistic environment, it was attached via waveguide switches to share diagnostic access with the existing TFTR fluctuation reflectometer[2], an instrument that was specifically designed to investigate density fluctuations in the interior of the plasma. This system utilizes corrugated cylindrical waveguide to launch highly directional gaussian beams that are focused and directed into the plasma with scannable mirrors.

Differential-phase data obtained with this quasi-optical viewing system are shown in Figs. 2 and 3. For these measurements, the gaussian beams (transmitting and receiving) are aimed to intersect at R = 3.3 m, resulting in a saturated amplitude for the received signal whenever the reflection surface is in the range of 3.1 to 3.5 m, the region characterized by good overlap of the two beams. When the location of the plasma edge region, $R_0 + a$, is systematically scanned from 3.25 to 3.53 m, the differential-phase data changes in the expected fashion, as illustrated by the phase data in Fig. 2a. Note in particular that the differential phase typically shows a variation of only 2 to 4 fringes as the frequency is swept from 91 to 117 GHz. For most of this data, even the differential phase exhibits substantial phase fluctuations, with a typical magnitude of 1 radian rms or larger, but this does not present a serious problem in tracking the average trend in the phase. Edge-density profiles reconstructed from this data using an algorithm based on an extension of Doyle's method[3] are shown in Fig. 2b. Similar data for a selection of shots with the same plasma size but different density (resulting from variation in NBI power from 0 to 27.5 MW) are shown in Fig. 3, demonstrating the expected variation in the differential phase as the density is varied.

The differential phase can be considered as consisting of two contributions, one associated with the shape of the profile through the local density gradient-dependent plasma dispersion, and another arising from the location of the plasma edge region. For the data shown in Fig. 2, shifting the location of the plasma edge by $\leq$ 30 cm while maintaining nearly the same profile shape is expected to contribute $\leq$½ fringe to the total phase shift (i.e., the beat wavelength for 250 MHz frequency spacing is 1.2 m). This indicates that dispersive effects related to the profile shape represent the largest contribution to the differential phase. At the present time it is not clear to what extent these two contributions to the total phase can be separated. Although the reflectometer provides good information on the shape of the density profile in the edge region, it appears that the location of the plasma edge can be resolved only through detailed comparisons with other TFTR diagnostics.

Data obtained from full-sized ($R_0 + a$ = 3.6 m) ICRF-heated plasmas show a similar shape for the edge-density profile. Attempts to observe modification of the edge-density profile during ICRF heating have not revealed any measurable changes, suggesting that if changes are occurring they are local to the antenna environment.

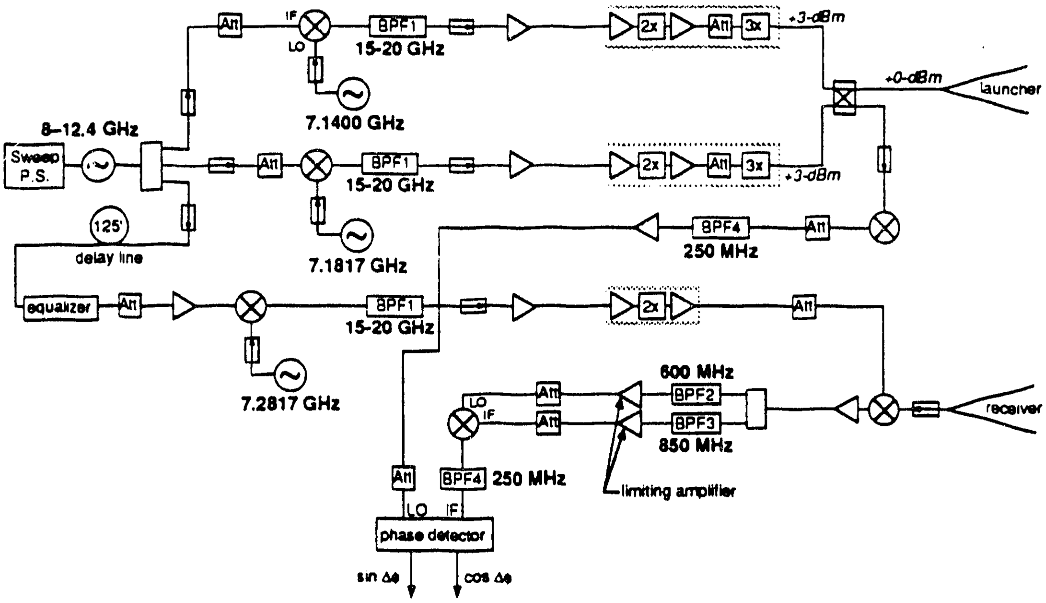

Fig. 1. A block diagram of the dual-frequency differential-phase reflectometer as configured for the proof-of-principle demonstration measurement on TFTR.

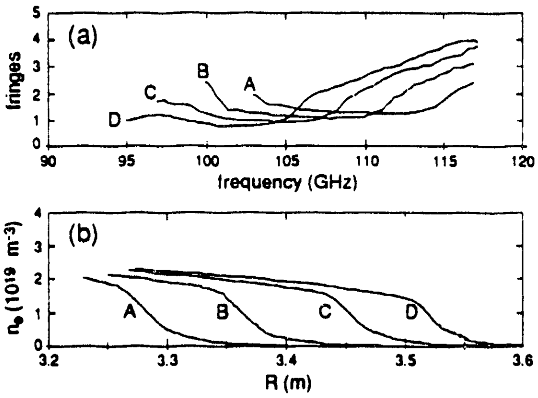

Fig. 2. (a) Measured differential-phase shift as a function of frequency and (b) reconstructed edge-density profiles for a plasma size scan where, for cases A, B, C, and D, the outer edge of the plasma (R_0 + a) is located at 3.25, 3.35, 3.44, and 3.53 m, respectively. Plasma conditions include B = 4.5 T (I_{tf} = 67 kA), I_p = 1.6 MA, $\overline{n_e}$ = 3.2–3.6 x 10^{19} m^{-3}, P_{NBI} = 22.5 MW, and P_{ICRF} = 0.

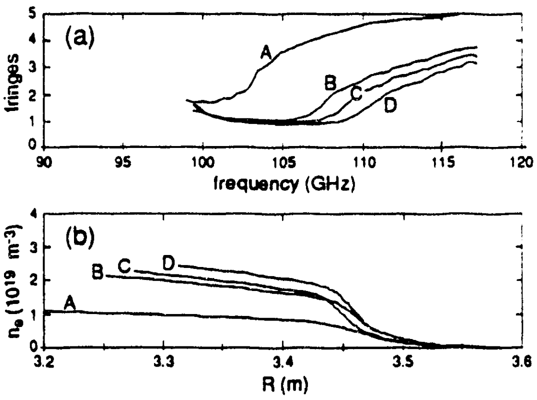

Fig. 3. (a) Differential-phase shift and (b) reconstructed edge-density profiles for a collection of shots where the density varies with the neutral beam power. Cases A, B, C, and D correspond to P_{NBI} = 0, 17.5, 22.5, and 27.5 MW and $\overline{n_e}$ = 1.2, 2.8, 3.2, and 3.7 x 10^{19} m^{-3}, respectively. Other plasma conditions include R_0 + a = 3.44 m, B = 4.5 T (I_{tf} = 67kA), I_p = 2.0 MA, and P_{ICRF} = 0.

NEW LAUNCHER AND WAVEGUIDE TRANSMISSION LINE

A new launcher and waveguide transmission line are presently being installed on TFTR. The bay-K ICRF antenna was designed with a central diagnostic port that provides access for the reflectometer launchers on the center axis of this two-strap antenna. To eliminate the effects of spurious reflection on the reflectometer phase measurements, a pair of oversized WR-90 rectangular waveguides are used for the transmitting and receiving antennas. The launcher apertures are recessed 3 mm behind the front surface of the Faraday shield for the ICRF antenna. Stainless steel waveguides are necessary to limit disruption forces; a single quartz window is used for the vacuum feedthrough. "Tall-guide" polarization is used to achieve acceptable waveguide cross-coupling (<- 40 db measured) between the closely spaced waveguides at the vacuum window.

With the exception of a downtapered section of WR-10 waveguide immediately outside the vacuum window, which serves to filter higher-order modes, the remainder of the waveguide run consists of 26 m of WR-90 waveguide leading to the reflectometer electronics located in the test cell basement. Transmission losses are reduced more than 50% by using the tall-guide polarization, resulting in an estimated round-trip transmission loss of 12 db, excluding the window/launcher assembly. For the tall-guide polarization, miter bend losses are measured to be approximately 0.4 and 0.8 db for the H-plane and E-plane bends, respectively.

CONCLUSION

Initial proof-of-principle measurements demonstrate that the dual-frequency differential-phase reflectometer is an effective way to measure the electron density profile in the plasma edge region where density fluctuations are large. An ICRF-antenna-mounted launcher and the associated waveguide transmission line are presently being installed in the bay-K ICRF antenna on TFTR. This will allow direct measurement of the edge-density profile within the high power density environment of the ICRF antenna, where density profile modification might be expected.

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