

## A Fixed Frequency Reflectometer to Measure Density Fluctuations at Aditya Tokamak

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**Abstract.** Amongst modern diagnostics of fusion plasmas, microwave methods, both passive and active, play an important role. Microwave Reflectometer is used to measure the plasma density and its fluctuations in fusion research device like tokamak. A fixed frequency (O – mode) microwave reflectometer at 22 GHz (cut – off density  $n_c = 6 \times 10^{12} \text{ cm}^{-3}$ ) has been designed, developed and used to measure the critical density layer and its fluctuations in Aditya tokamak. It can measure the plasma density fluctuations from  $r = 11$  to 22 cm for central electron density  $7.5 \times 10^{12} \text{ cm}^{-3}$  and more, respectively. The output signal of reflectometer is analyzed and compared with the density measurement from the microwave interferometer. When the density measured by interferometer is constant, then the fluctuations of local density are seen from the reflectometer signal. Analysis of initial results show that density fluctuation at  $r = 21$  cm in the main plasma has correlation time of about 8  $\mu\text{sec}$  and frequency spectrum is broad. Use of 22 GHz incident wave allows the observation of density fluctuation with wave number in the range of  $0 - 9.2 \text{ cm}^{-1}$  from the reflecting region at the receiving horn. Radial variation of the fluctuation level is observed from 5% to 22% for minor radius 11 to 22 cm, respectively.

### 1. Introduction

The tokamak is a device designed to magnetically confine hot plasmas in a toroidal configuration, with the eventual purpose of producing controlled thermonuclear fusion. The fixed frequency reflectometry diagnostic is widely used to determine the electron density fluctuations in tokamak [1-3]. Its principle is based upon the radar technique and determines the phase shift of microwave propagating into the plasma and reflected at cut-off layer. Physically, it possesses several advantages: a good spatial and temporal resolution ( $\delta r < 1 \text{ cm}$  and  $\delta t < 5 \mu\text{s}$ ) [4]. Technically, the reflectometry needs a very small access to the vacuum vessel. These principal characteristics make reflectometry an important diagnostic for the present and future tokamaks like SST-1 [5] and ITER [6]. In this paper, design, development and use of a fixed frequency reflectometer as a diagnostic to study the electron density fluctuations is reported.



## 2. Reflectometry

### 2.1. Basic Principle

Reflectometry relies on the total reflection of electromagnetic waves by plasma when the local refractive index  $\mu$  equals zero. For the ordinary mode waves ( $\mathbf{E} \parallel \mathbf{B}_T$ ), this occurs when the wave frequency  $f = f_p$  given by

$$f_p = \left( \frac{n_e e^2}{4\pi^2 \epsilon_0 m_e} \right)^{1/2} \quad (1)$$

where,  $e$  = charge of the electron,  $m_e$  = mass of the electron and  $\epsilon_0$  = permittivity of free space. This corresponds to a critical reflecting density  $n_c$ , where

$$n_c = f^2 \left( \frac{4\pi^2 \epsilon_0 m_e}{e^2} \right) = \frac{f^2}{80.6} \text{ m}^{-3} \quad (2)$$

The phase change that a wave will undergo in propagating through plasma to cut-off layer, being reflected at the cut-off layer, and propagating back out of the plasma is given by

$$\phi = \left( \frac{2\omega}{c} \right) \int_r^{r_c} \mu(r) dr - \frac{\pi}{2} \quad (3)$$

This equation shows that the phase change can result from three possible sources:

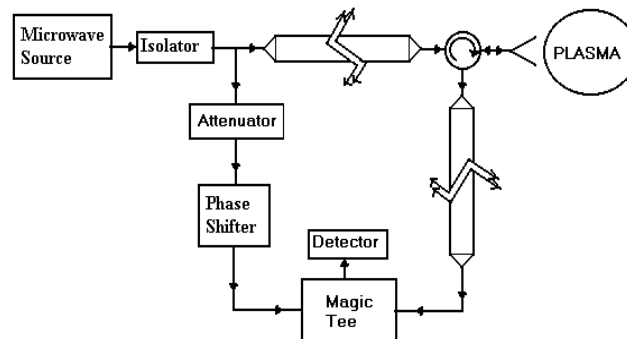
1. Movement of the cut-off layer  $r_c$
2. Changes in the refractive index  $\mu(r)$
3. Changes in the probing frequency  $\omega$

Thus if the probing frequency of reflectometer is fixed and plasma refractive index is constant, then the change in the phase will be due to the movement of cut-off density layer which is known as density fluctuations.

A fixed frequency (O – mode) microwave reflectometer at 22 GHz (cut-off density  $n_c = 6 \times 10^{12} \text{ cm}^{-3}$ ) has been designed and developed to measure the critical density layer and its fluctuations at tokamak ADITYA. The plasma density fluctuations has been measured from  $r = 11$  to 22 cm for central electron density  $7.5 \times 10^{12} \text{ cm}^{-3}$  and more, respectively.

### 2.2. Design

The block diagram of a 22 GHz reflectometer is shown in figure 1. A Gunn oscillator at 22 GHz is used as a microwave source, whose output is about 70 mW. The source along with power supply is kept 4 meter away from the center of the tokamak Aditya. At this distance, magnetic fields effect on the isolator is negligible. The output of the source is connected to an isolator whose isolation is more than 35 dB. The output of isolator is divided by using 10 dB directional coupler (D.C) in such a way that 90% power should go to plasma path and 10% should go to reference path. The K – band waveguide of 4 m length is used to carry the power output to the horn antenna (Gain = 20 dB) and reflected power to the power combiner (Magic Tee). The same antenna is used for transmitting and receiving purposes. A circulator is used to get reflected signal from the antenna. A magic tee is used to see the interference between reference path and plasma path signal and output of this will go to the detector. An attenuator (A) and a phase shifter (P.S) are used in reference path to make power levels equal and set initial phase shift to zero between two paths, respectively. Homodyne detection technique is used to measure the cut-off density layer and its fluctuations. Electrical breaks are provided at regular intervals in the waveguide and the supporting structure to avoid close loop formation. A Teflon lens (diameter = 100 cm) is used in front of horn to make a parallel beam of microwave before it enters to the plasma through a 100 CF vacuum window of Kodial glass. The sensitivity of the detector is 1000 mV/mW. The output of the detector is amplified with a gain of 10 and digitized by a digitizer at the sampling rate of 1 MHz.

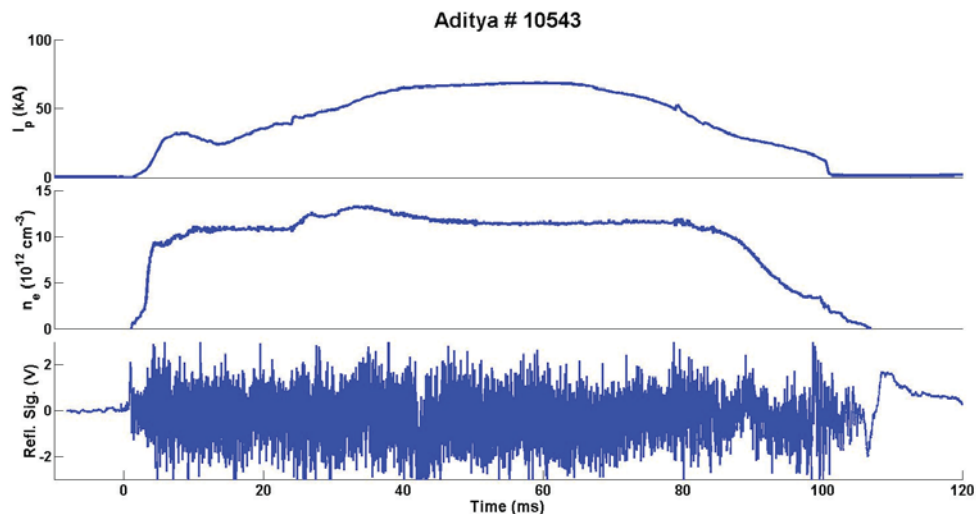


**Figure 1.** The block diagram of 22 GHz reflectometer

### 3. Results and Discussion

For this experiment, the Aditya operating parameters are the toroidal magnetic field  $B_T \sim 0.75$  T, the neutral base pressure  $P \sim 3.5 - 5.0 \times 10^{-5}$  Torr, the plasma current  $I_p \sim 60 - 80$  kA, the discharge duration  $t \sim 60 - 120$  ms and the chord averaged density  $n_e \sim (0.5 - 1.5) \times 10^{13} \text{ cm}^{-3}$ .

The time evolution of the plasma current, the chord averaged plasma density and the reflectometer signal is shown in figure 2. Initially (1.5 – 3.0 ms), a few small fringes are seen in reflectometer output, which is due to the phase shift introduced by the low density plasma which allows the wave to go up to the inside wall of the vessel and get reflected. When the plasma density reaches to the cut off density, the wave is reflected from the cut off layer and we start getting the higher amplitude signal.

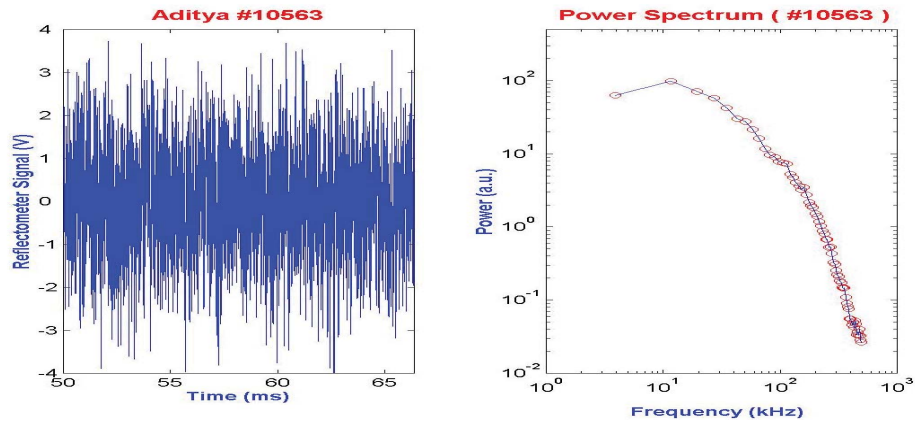


**Figure 2.** The plasma current, the plasma density and the reflectometer signal vs time

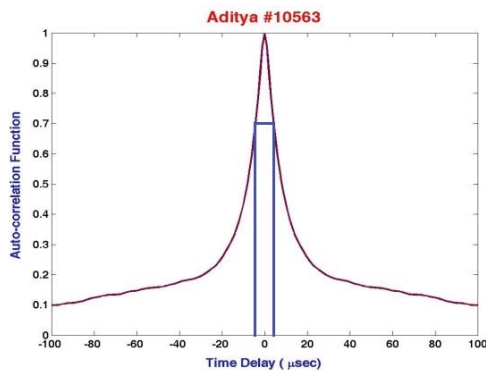
As the density evolves, cut off layer starts moving outside, and fringes of increasing amplitude due to the layer movement are seen. Chord averaged density at the center channel remains constant between 45 – 80 ms at about  $1.2 \times 10^{13} \text{ cm}^{-3}$ . The cut-off density layer for 22 GHz ( $n_c = 6 \times 10^{12} \text{ cm}^{-3}$ ) appears at  $r = 21$  cm. The reflectometer signal between 45 and 80 ms carry the information of the fluctuation of the cut-off density layer.

The power spectrum analysis (figure 3) shows that the frequency spectrum is broadband. Figure 4 shows the auto correlation function vs time delay. The auto-correlation time is  $\sim 8 \mu\text{s}$ . The use of 22

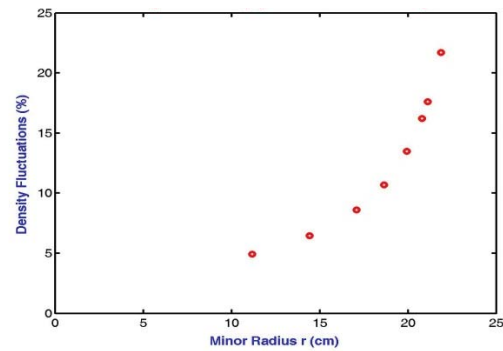
GHz incident wave allows the observation of density fluctuations with wave number in the range of 0 – 9.2 cm<sup>-1</sup> from the reflecting region at the receiving horn.



**Figure 3.** The Reflectometer signal and its power spectrum



**Figure 4.** The correlation function vs time



**Figure 5.** The spatial variation of the density fluctuation

The density fluctuation levels are found by using discharges of different central chord averaged densities ( $n_e \sim 0.5 - 1.5 \times 10^{13} \text{ cm}^{-3}$ ). Figure 5 shows the spatial variation of the density fluctuation level at Aditya. The radial variation of the fluctuation level is observed from 5% to 22% for the minor radius 11 to 22 cm, respectively. The amplitude of the fluctuation level increases exponentially from the center of the plasma to the edge of the plasma.

#### 4. Conclusion

A fixed frequency (O – mode) microwave reflectometer at 22 GHz ( $n_e = 6 \times 10^{12} \text{ cm}^{-3}$ ) is designed, developed and used to measure the plasma density fluctuations. The plasma density fluctuations from  $r = 11$  to 22 cm for different central electron densities is measured. The evolution of reflectometer output signal is studied and compared with microwave interferometer signal. The measured auto-correlation time of the reflectometer signal is  $\sim 8$  ms. The power spectrum analysis shows that the frequency spectrum is broadband. The use of 22 GHz incident wave allows the observation of density fluctuations with wave number in the range of 0 – 9.2 cm<sup>-1</sup> from the reflecting region at the receiving horn. The radial variation of the fluctuation level is observed from 5% to 22% for the minor radius 11 to 22 cm, respectively.

**References**

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