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Development of the W-band density profile and fluctuation reflectometer on EAST

Y.M. Wang, X. Gao*, B.L. Ling, S.B. Zhang, T. Zhang, X. Han, S.C. Liu, Z.X. Liu, Y. Liu, A. Ti, EAST Team

Institute of Plasma Physics, Chinese Academy of Sciences, P.O. Box 1126, Hefei, Anhui 230031, People's Republic of China

HIGHLIGHTS

- A X-mode W-band reflectometer is designed and installed on Experimental Advanced Superconducting Tokamak (EAST) for the first time.
- Both density profile and fluctuations can be measured by the newly developed reflectometer.
- The core density profile has been measured in high magnetic field condition together with V-band reflectometer.
- Sawtooth precursor has been measured by fluctuation reflectometer in the low magnetic field condition.

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ABSTRACT

A X-mode polarized W-band reflectometer for plasma density profile and fluctuation measurement is designed and installed on EAST. In measuring the density profile, a voltage controlled oscillator (VCO) is used as the source, allowing a high temporal resolution measurement. The density profile in a plasma with high magnetic field (3.0 T) has been measured by combination of V- and W-band reflectometers. For fluctuation measurements, a frequency synthesizer is used instead of the VCO as a microwave source. The core density fluctuations during sawtooth activity are measured and analyzed.

1. Introduction

Microwave reflectometry is an offspring from radar techniques used in ionospheric studies [3,1,2]. The plasma density is inferred from the group delay of electromagnetic waves that are reflected in an inhomogeneous plasma at the place where the refractive index goes to zero [4,5].

The low injection power of the probing microwave beam makes reflectometry a non-perturbative method for measuring the electron density profile. This diagnostic is used on most of the fusion devices, such as JET [6], Tore Supra [5], DIII-D [7,8], ASDEX Upgrade [9] and LHD [10]. Due to its high temporal and spatial resolution, the reflectometry has been an important tool for physical studies such as: H-mode physics [11], transport behavior [12] and magnetohydrodynamic (MHD) instabilities [13]. For the density profile measurement, the accuracy is seriously deteriorated by density fluctuations. The ultra fast sweeping reflectometer can overcome this deterioration by "freezing" the fluctuations [14].

In addition, the density fluctuation at the cutoff can be derived from the phase fluctuation of the reflected wave. The fluctuation reflectometer has been used as a powerful tool for turbulence study related to magnetohydrodynamic (MHD) activities [15,16].

The Experimental Advanced Superconducting Tokamak (EAST) is a full superconducting toriodal device with a major radius (R) of 1.75m and minor radius (a) of 0.45 m. Presently, the main auxiliary heating method on EAST is RF heating using lower hybrid wave

* Corresponding author. Tel.: +86 0551 65593108
E-mail address: xgao@ipp.ac.cn (X. Gao).

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(LHW) and ion cyclotron resonance heating (ICRH) and thus the magnetic filed (B_T) at the major radius is usually operated from 1.6 T to 2.0 T for optimizing the plasma–wave coupling. A V-band (50–75 GHz) X-mode reflectometer has been developed on EAST and can provide routine measurements of the edge density profile [1]. The neutral beam injection (NBI) system and electron cyclotron resonance heating (ECRH) have been designed and will be installed on EAST in the near future. It is expected that B_T will be from 2.5 to 3.0 T when the plasma is heated by above heating methods and the V-band reflectometer can only reach the very edge region of plasma. In order to measure the density profile inside the plasma, a W-band reflectometry in the frequency range of 75–110 GHz has been developed on EAST. In this paper, the W-band reflectometer setup and a few experimental results are presented.

This paper is organized as follows: the experimental setup of W band reflectometer system on EAST is described in Section 2, and the experimental results are given in Section 3. Lastly, the summary and future plans are presented in Section 4.

2. Experimental setup

2.1. The system of the W band reflectometer

The schematic of the W-band reflectometer is shown in Fig. 1.

Source: A voltage controlled oscillator (VCO) driven by an arbitrary waveform generator (AWG) is used as the source for the density profile measurement. The output microwave frequency of VCO is from 11.5 to 18.5 GHz and the power of these waves is from 21 to 24 dBm. The sweep rate can reach up to 50 kHz, however 5 kHz is often used because of the limitation of the data acquisition system. The linear frequency sweep of the VCO is achieved by utilizing a nonlinear voltage output of AWG. For density fluctuation measurement, a low phase noise frequency synthesizer is used as the microwave source and the out power from the synthesizer is about 21 dBm. A power divider is used to split the microwave beam. One beam is used as probing arm and the other is used as reference arm.

Probing arm: A single sideband modulator (SSBM), which is considered to be the key component in heterodyne reflectometry system [17], is used to modulate the probing wave frequency. The SSBM used here is from Miteq Inc., and the side band suppression of both carrier frequency and lower sideband are larger than −25 dBc. In the SSBM, the incoming frequency F is combined with a modulation frequency f_m, then the upper sideband $F+f_m$ configuration is used as the output. In the W-band reflectometer, a 100 MHz wave generated by a quartz oscillator is used as the modulation frequency. The modulated probing wave is upconverted by an active sextupler providing frequency coverage between 69 and 111 GHz with an output power between 8 and 12 dBm and then launched into the plasma though Gaussian optic lens antennas (GOLA).

Reference arm: After the divider, a 3-meter delay line is used to compensate the phase delay on the probing arm. A sextupler is used after the delay line, and then the microwave is upconverted to the W band frequency range as the reference wave. The reference wave is mixed with the reflected wave from plasma. A ±50 MHz band pass filter is used after the mixer, suppressing the unwanted sidebands.

Antenna: The distance between the antenna and the vacuum window is about 2 cm, and the distance between vacuum window and plasma edge is about 1.7 m. As the probing wave propagates to the core of the plasma, a large attenuation is induced. The GOLA has a high gain (> 33 dBi), which helps to improve the signal-to-noise ratio.

I/Q detection: An I/Q demodulator is used to detect the in-phase (I) and quadrature (Q) signals. A complex signal is constructed from the I and Q signals and then the wave amplitude and phase can be determined.

2.2. Frequency band needed on EAST

The microwave is reflected in magnetized plasma at the position where the refractive index, given by the Appleton–Hartree equation [18], goes to zero. For a X-mode polarized electromagnetic wave, propagating in the direction perpendicular to the magnetic field, the cutoff frequency of the probing wave is given by

$$\omega_{R,L} = \frac{1}{2}\left[\pm\omega_{ce} + \sqrt{4\omega_p^2 + \omega_{ce}^2}\right], \tag{1}$$

where ω_{ce} denotes the electron cyclotron emission frequency and ω_p denotes the plasma frequency. On EAST, the probing wave is launched into the plasma at the equatorial plane in the low field side (LFS) of the plasma and thus the cutoff of the wave is at the place where the probing frequency equals the local right hand cutoff frequency (ω_R).

2.3. Bench test of the W band reflectometry

Since the output wave frequency of VCO depends nonlinearly on the driving voltage, a nonlinear waveform of the voltage is applied in order to acquire a linear dependence of the frequency on time. This has been described in detail in Reference 1.

The delay time of the probing signal is given by

$$\tau = \frac{1}{2\pi}\frac{d\phi/dt}{df/dt} = \frac{f_b}{df/dt}, \tag{2}$$

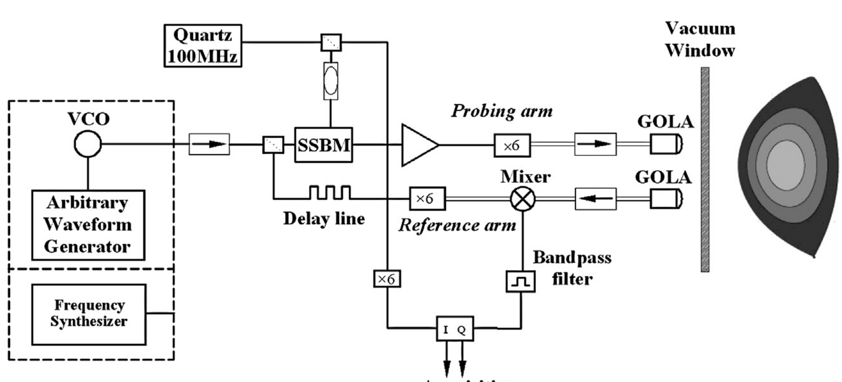

Fig. 1. The schematic of the W-band X-mode reflectometer on EAST. I: The VCO is driven by an arbitrary waveform generator is used to perform density profile measurement. II: The frequency synthesizer is used for fluctuation measurement.