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Q-Band X-Mode Reflectometry for the Diagnostics of ICRF Evanescent Layer

Chan Yong An*, Sonjong Wang, Dongjin Ku, Min Park, Sun Ho Kim and Sung Kyu Kim
Korea Atomic Energy Research Institute, Daedeokdaero 1045, Yuseong-gu, Daejeon, 305-600, Republic of Korea
*Corresponding author: cyan@kaeri.re.kr

1. Introduction

For the ICRF (Ion Cyclotron Range of Frequency) heating of KSTAR (Korea Superconducting Tokamak Advanced Research) plasma, measurement of edge plasma density is important for increasing the efficiency of RF transmission into the plasma where resonance exists and for protecting antenna from high energy particles. Therefore, FMCW (Frequency Modulated Continuous Wave) reflectometry with only one antenna has been developed for measurement of edge plasma density distribution. Until now most of reflectometry for the plasma diagnostics uses two antennas, one for emitting waves and the other for receiving them [1]. A reflectometry with single antenna is simpler than two antennas system for receiving the power reflected by the cut-off layer. The single antenna reflectometry uses directional coupler to couple emitting and receiving waves at the same device [2]. For testing the fabricated reflectometry, average plasma density of helicon device was measured

2. Theory

The transverse X-mode reflective index N_X can be written as

$$N_X = \sqrt{1 - \frac{{\omega_{p,e}}^2}{\omega^2} \frac{\omega^2 - {\omega_{p,e}}^2}{\omega^2 - {\omega_h}^2}} \tag{1}$$

where $\omega_{p,e}$ is the electron plasma frequency, ω_h is the upper hybrid frequency, and ω is the frequency of the incident wave [2]. The reflectometry is based on the measurement of delay time of reflected wave which passed through the plasma. Equation (1) shows that the waves cannot travel through the plasma when the reflective index becomes zero. If plasma density is so low that no reflrection occurs in the plasma, wave would be reflected at the reflection wall of plasma chamber. If N_x is assumed to be constant N_{av}, delay time τ is

$$\tau = \frac{N_{av}}{c} l + \tau_w \tag{2}$$

where l is total pass length of incident and reflected wave and τ_w is delay time of waveguide system. Since magnetic field is so low that upper hybrid frequency is similar to the plasma frequency ${\omega_h}^2 \approx {\omega_p}^2$, equation (1) may be approximated by

$$n_{av} = \frac{m_e \omega^2}{4\pi e^2}\left(1 - {N_{av}}^2\right) \tag{3}$$

Therefore measuring delay time, we can derive the line averaged density n_{av}.

Delay time of linearly modulated FMCW system can be inferred by beating frequency f_{IF} as

$$\frac{\tau\left(f_f - f_i\right)}{T} = f_{IF} \tag{4}$$

Where linear modulating parameters f_i, f_f and T are starting frequency, final frequency and sweep period, respectively.

3. Design for FMCW reflectometry

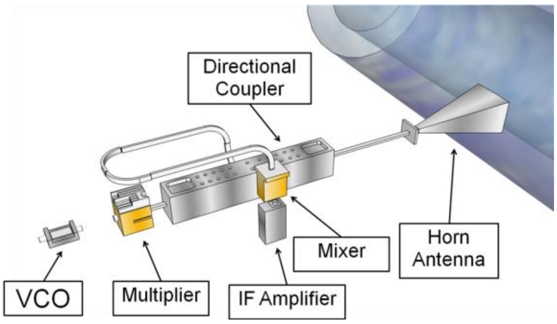

Fig. 1. The design of the reflectometry for using one antenna.

Fig. 1 shows the reflectometry with single antenna. Output frequency of VCO is proportional to tuning voltage. Therefore, when triangle wave is applied to VCO, sawtooth frequency modulated signal can be obtained. The output frequency of VCO is multiplied by four times by frequency multiplier. The multiplied signal is divided to two signals when it passes though directional coupler. One signal is used as Local Oscillator for the mixer and the other is used for the incident wave to plasma. The reflecting signal from plasma is coupled by same method. The coupled RF signal is fed to mixer to generate beating frequency f_{IF}.

4. Experiment

4.1. The measurement of delay time of waveguide system

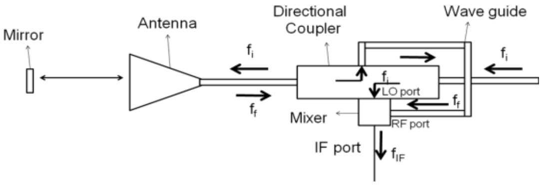

Fig. 2. Set-up of the calibration.

For the relative calibration of the reflectormetry, delay time τ_w of waveguide system was measured using reflecting mirror at the know positions as seen in Fig. 2. Fig. 3 shows measured and simulated IF frequency as a function of relative mirror distance. These data are also compared with ideal IF frequency.

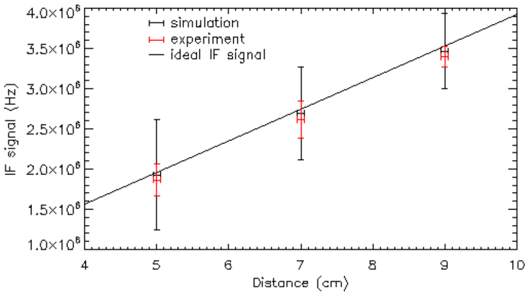

Fig. 3. IF frequency of reflected signal from mirror at known distance

4.2. Helicon plasma source

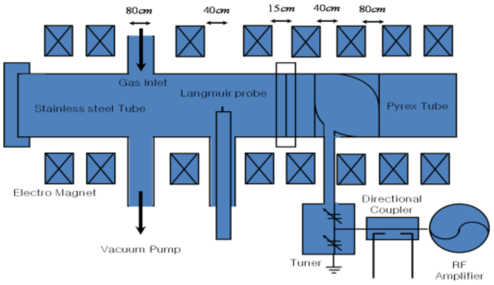

Fig. 4. Schematics of helicon source

Helicon plasma source seen in Fig. 4 is used to test the fabricated reflectometry [4]. Applied RF power is 10 MHz 800 W. Ar gas pressure is 9×10^3 mbar and axial magnetic field is 350 G

5. Result

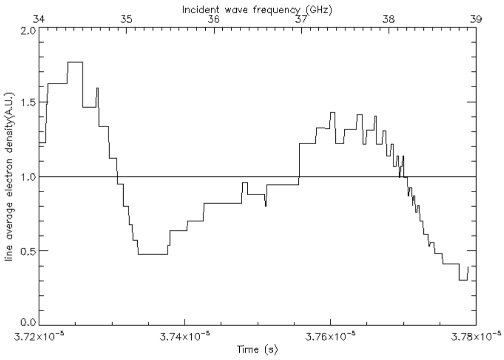

Fig. 5. Plasma density differences due to VCO of the non-linearity.

Using equation (4), line averaged electron density was derived by measurement of IF frequency. Fig. 5 shows fluctuation of constructed data. Because the time window is so narrow, it is difficult to understand the waveform as a density fluctuation. In addition, the waveform is repetitive and the period is similar to the frequency sweeping period. Therefore it is believed that the waveform in Fig. 5 is an artifact arose by non-linearity of VCO output frequency. So, the compensation of the tuning voltage of VCO will be made in near future.

6. Conclusions

FMCW reflectometry is being developed for the measurement of edge density of fusion plasma. Fabricated reflectometry was calibrated by measuring distance of a mirror and tested by measuring average density of helicon plasma. The reflectometry will be used to measure density profile in front of ICRF antenna.

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