Observation of Energetic Particle Mode by Using Microwave Reflectometer

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Abstract
Two heterodyne reflectometer systems are utilized for the fluctuation measurement in the Large Helical Device (LHD). By using the extraordinary polarized wave, we can measure the corresponding value to the combined fluctuation with the electron density and the magnetic field in the plasma core region even if the radial electron density profile is flat. E-band system has three channels of fixed frequencies of 78, 72, 65 GHz. The system is very convenient to observe magnetohydrodynamics (MHD) phenomena such as energetic particle driven Alfvén eigenmodes, even if the system works as an interferometer mode. The detailed behaviour of the energetic particle mode is studied when low-*n* MHD burst is occurred. It seems to be caused that the spatial distribution of high energy particle is changed by such a MHD-burst. Also to know the radial distribution of MHD mode, frequency swept R-band reflectometer is applied for the first time. It seems to be successfully detected the energetic particle mode and toroidal Alfvén eigenmode.

1. Introduction

In the burning plasma energetic alpha particles enhance magnetohydrodynamics (MHD) modes such as toroidal Alfvén eigenmodes (TAEs). On the other hand MHD mode affects the alpha particle transport and changes plasma confinement. Therefore energetic particle driven MHD instability has been studying in several magnetic confinement devices [1-4]. Usually MHD phenomena are observed by magnetic probes and the excellent analytical technique is developed to know toroidal and poloidal mode number and travelling direction etc. Also theoretical analysis using three dimensional code has been developing [5]. For the comparison between the simulation code result and the experimental result, it is important to measure directly the radial distribution of these modes.

In Large Helical Device (LHD [6]) recently we have been applying two types of microwave reflectometer system for measuring the radial distribution of the fluctuation, because the microwave reflectometer has a potential of the localized measurement by using the cut-off effect in the plasma core. One system is the multi-channel heterodyne fixed frequency reflectometer [7]. Recently the real-time data acquisition system is applied with the sampling rate of up to 10 MSample/sec by using a compact-PCI based digitizer. Then it can measure the density and magnetic fluctuation in the core region during the whole plasma discharge. And another one is the frequency swept reflectometer system. When the plasma condition seems to be steady during the frequency sweeping period, the radial profile could be measured each sweep in one plasma discharge. By using these reflectometers it is quite easy to observe MHD phenomena such as energetic particle mode and Alfvén eigenmodes. In this paper we present these two reflectometer systems and some experimental results.

2. Frequency Fixed E-band Reflectometer System

E-band fixed frequency heterodyne reflectometer system is utilized for the fluctuation measurement [7]. Currently the system has three channels of fixed frequencies of 78, 72, 65 GHz. Power combined three microwaves are travelling to/from the LHD by using a corrugated waveguide for avoiding the transmission loss. The simplified super heterodyne detection technique is used for the receiver system. In LHD the real-time data acquisition system has been able to be utilized and the sampling rate is up to 10 MSample/sec by using a compact PCI based digitizer [8]. The system is very convenient to observe MHD phenomena such as energetic particle driven Alfvén eigenmodes, launching the extraordinary polarized wave. In Fig. 1 the temporal behaviours of the reflectometer signal of 78 GHz and magnetic probe signal and these power spectra are shown. Coherent spectra of around 8 and 16 kHz are caused by low-*n* mode oscillation. In the range of 100~150 kHz there are a lot of coherent

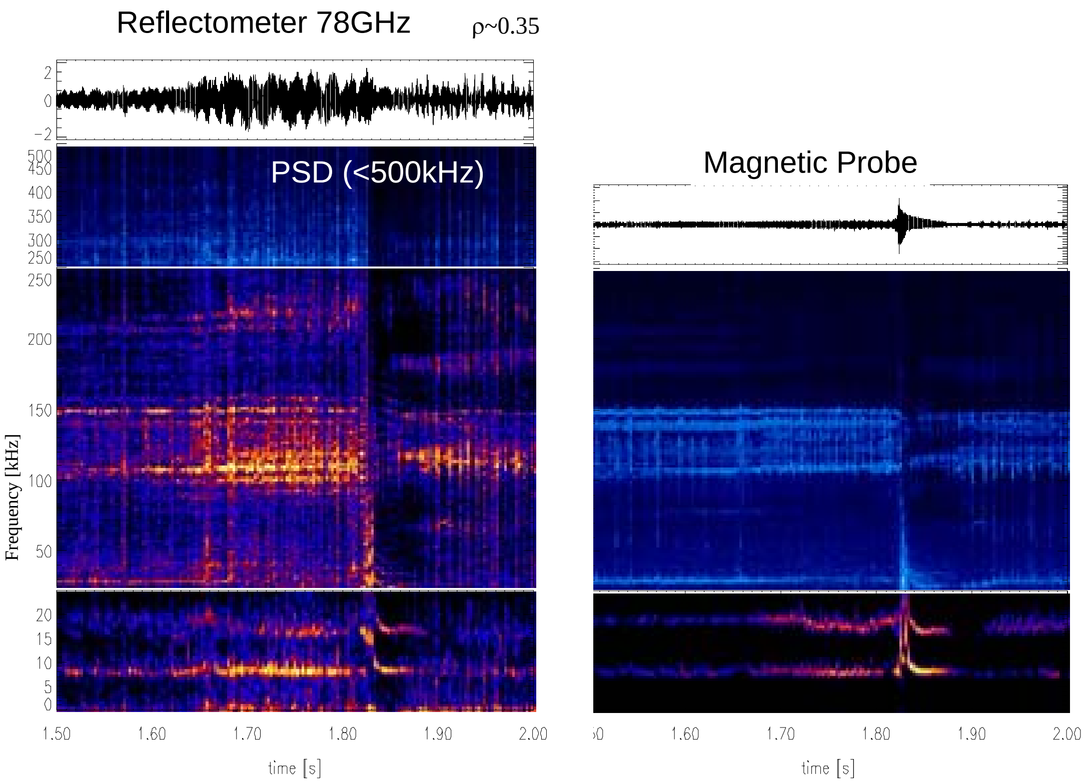

Figure 1 Time evolution of reflectometer signal and frequency spectrum (Left) and these of magnetic probe signal (right)

mode. These mode are identified the n=1 (n: toroidal mode number) TAE mode by the magnetic probe analysis. Also on the reflectometer signal it is observed higher mode around 230 kHz. Just after t=1.82s MHD-burst is occurred and TAE mode frequency components are rapidly disappeared and then passing 0.02s these mode are revived. This sudden disappearance may be caused that the distribution of high energy particle is changed by such a MHD-burst. In this experiment the birth source of energetic particle is generated by the neutral beam and this injection of neutral beam is kept constant during this phenomenon is occurred. Therefore the TAE mode is re-exited quickly and then it keeps to a next burst.

3. Frequency Modulated R-band Reflectometer System

To know the radial distribution of fluctuation there are two methods in reflectometry. One is the multi-channel system, and another is the wide band frequency source system. For the latter system, source frequency sweeps step by step in the whole frequency range. The step width is limited by the characteristic time of the desired fluctuation frequency. Of course, during the frequency modulation, the plasma condition and fluctuation level are assumed to be constant. Figure 2 shows the schematic of frequency modulated reflectometer system. The system uses voltage controlled oscillator (VCO) as a source. The output frequency of this source is easily changed by the external controlled signal. The output wave is amplified and also this frequency is multiplied by two. The reflected wave is mixed with a local wave for the heterodyne detection and IF signal is amplified and detected. Data acquisition system is the same as the previous E-band reflectometer system.

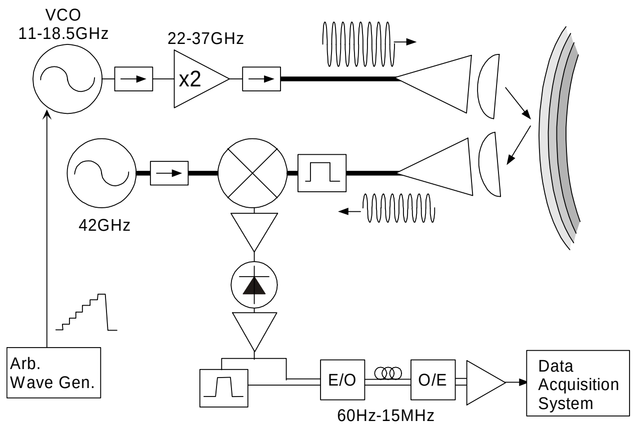

Figure 2 Schematic of FM-CW Reflectometer

The experiment is carried out that the axial magnetic field strength is 1.0 T, the averaged electron density is under $0.5\times10^{19}m^{-3}$, and neutral beam is injected with constant. The source frequency is swept full range every 200ms and the number of the stair step is 20. Each time of the launching frequency is 10ms and data sampling rate is 1μs, then the data

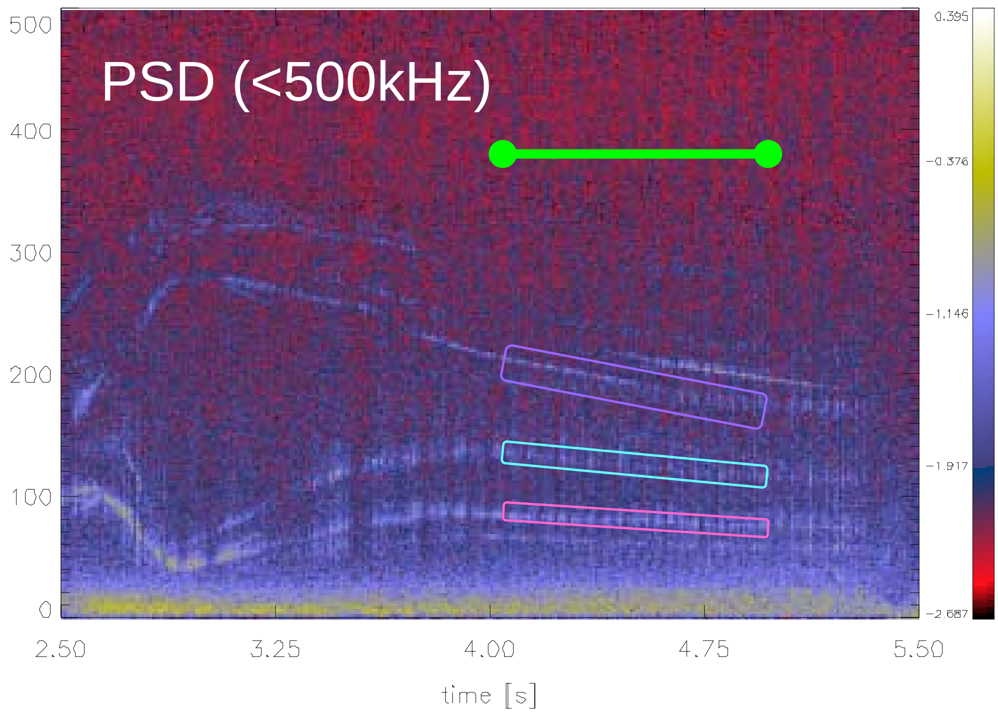

Figure 3 Frequency spectrum of interferometer mode CW Reflectometer

point is 10,000 and the frequency resolution is 100Hz. It is enough to observe the MHD phenomena such as TAE. Figure 3 shows the frequency spectrum of the previous frequency fixed 78GHz reflectometer signal. In this plasma condition there is no cut-off layer of 78GHz and this system is operated as an interferometer mode. We can see several continuous coherent frequency components. Figure 4 shows the radial profile of the fluctuation strength of the frequency swept reflectometer signal during *t*=4.0-4.8s (4 periods). It can be obtained that the frequency component around 200kHz is large near at ρ=0.8 and the other component around 150kHz is localized in the plasma centre. Here the meaning of the data points which are located under ρ=0 is that these frequency waves are not reflected from the plasma and they are come back from the opposite wall.

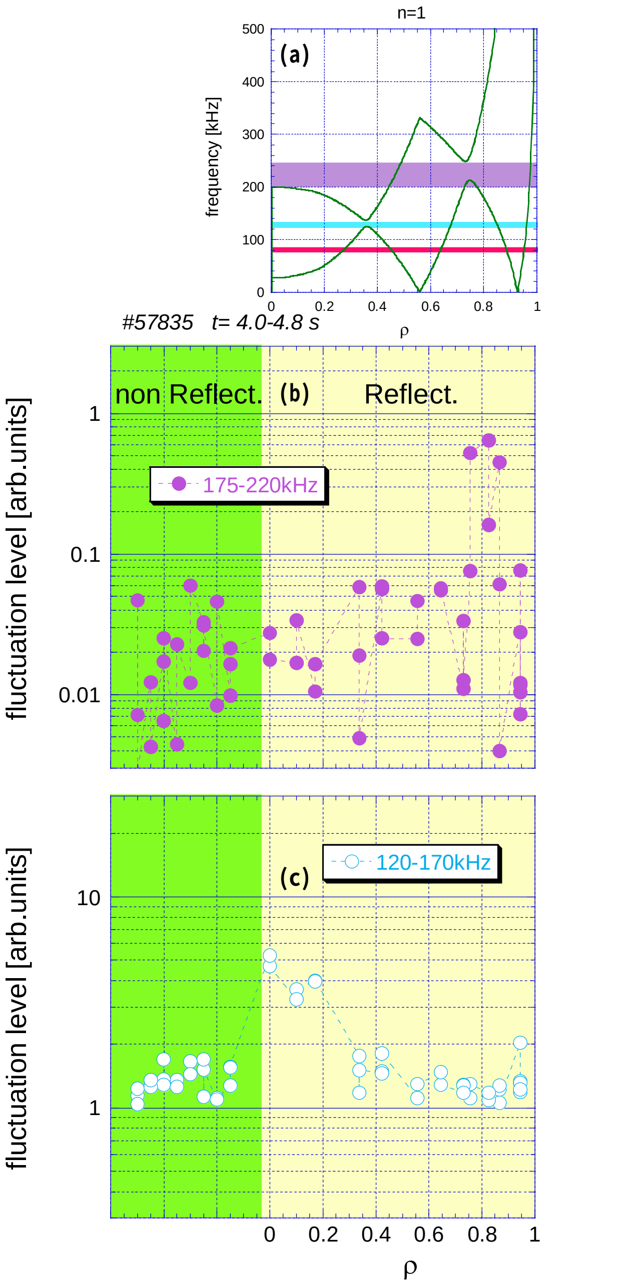

Figure 5 (a) Shear Alfvén spectra for n=1 and Radial profile of the fluctuation component of FM-CW reflectometer in the range that (b) 175-220 kHz and (c) 120-170kHz

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