§8. Development of Electron Cyclotron Emission Imaging System on LHD

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A combined system of Microwave Imaging Reflectometry (MIR) and the Electron Cyclotron Emission Imaging (ECEI) has been developed for Large Helical Device (LHD). Microwave imaging diagnostics has potential to observe fluctuations of electron density and electron temperature profiles in magnetically confined high temperature plasmas. When the plasma density and temperature are sufficiently high, the Electron Cyclotron Emission (ECE) is a black body radiation in magnetically confined plasmas. The electron temperature profile can be determined by measuring intensity of each frequency of the ECE, since the ECE frequency corresponds to the radial position. By using a 1-D receiving antenna array, the 2-D ECE profile (radial and poloidal directions) can be obtained. The electron temperature is considered to be equal on the same magnetic flux surface so that ECE imaging (ECEI) can be one of the most powerful diagnostics to investigate MHD instabilities.

Developed ECEI system is equipped with a same imaging optics of MIR. Therefore, this system can observe both density and temperature fluctuations simultaneously. As an example, in LHD Plasma with n_{e0} = 3x10^{19} m^{-3} and B_{ax} = 2.75 T (R_{ax} = 3.6 m), the second harmonic ECE of 96.5 - 104.5 GHz corresponds to the observation range of 4.44 to 4.55 m in the major radius.

Our MIR / ECEI system consists of three devices as follows: 1) imaging optics, 2) horn-antenna mixer array (HMA), 3) multi-frequency detector.

1) The optical system has three optics, illumination optics for MIR, focusing optics and local oscillator (LO) optics. The MIR and ECE signals from plasma are focused on HMA with the focusing optics. The focusing optics is shared between MIR and ECEI, since the same plasma position can be measured. Since LO frequencies for ECEI and MIR are different, they are radiated with different horn antenna and are mixed with an acrylic beam splitter (BS). The focusing optics is designed as the LO wave illuminates the whole area of the stack of HMAs for MIR and for ECEI and a point of plasma position is focused to a single antenna element of HMA. In this system, a 2-D HMA and 1-D HMA are adopted for MIR and ECEI, respectively.

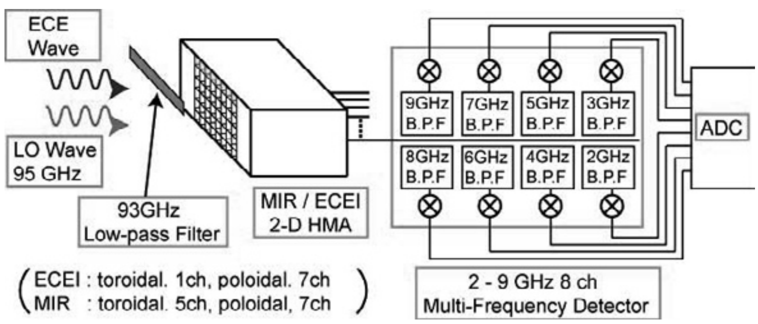

Fig.1 ECEI Antenna and IF system

2) Recently, we have developed a horn-antenna mixer array (HMA) for the V-band (50 - 75 GHz) MIR. Since an end-fire type antenna element is adopted in HMA, 2-D HMA can be easily composed by stacking 1-D HMAs. While HMA was designed to use with the frequency range of V-band, it has a good response in required frequency range, 75 – 110 GHz (W-band). In HMA, horn antenna receives both ECEI signals and LO signal, and mixer generates IF signals.

3) The frequency spectrum of ECE is detected with the multi-frequency detector composed on a high frequency PCB using the microstrip line technology. This type of detector was adopted in the KSTAR radiometer system. It is a more compact and low-cost solution than using coaxial band-pass filters. It consists of 3 sections as follows: IF amplifiers (DC - 12 GHz, 30 dB); the 8-ch band-pass filter (BPF) bank; power detectors. IF amplifier uses the same MMIC amplifier adopted in HMA. The 8-ch BPF bank is made by edge coupled filters, which are resonator lines coupled with the main transmission line. The length of the resonator line is about a quarter wavelength of the central frequency of each BPF. The central frequencies are set at 1 GHz step up to 9 GHz from 2 GHz. The designed bandwidth of each BPF is 500 MHz. The power detector is a zero bias Schottky diode showing positive peak detection. Each circuit is matched with own frequency. The sensitivity is about 1 V/mW (2 GHz detector). It seems that there are good separations without spurious response. On the other hand, sensitivity decreases as the frequency increases.

An example of an ECE signal in the preliminary ECEI experiment, which uses the 1-D HMA is shown in Fig.2. In this case, additional amplifiers (50dB, 2 - 18 GHz) are inserted between the HMA and the multi-frequency detector. The waveform of the ECE signal at 101 GHz which corresponds to R = 4.5 m, is similar to the waveform of the electron temperature measured by Thomson scattering at R = 4.483 m, when ECH is absent. This result indicates that the V-band HMA can be applied to the W-band (75 – 110 GHz) ECEI receiver.

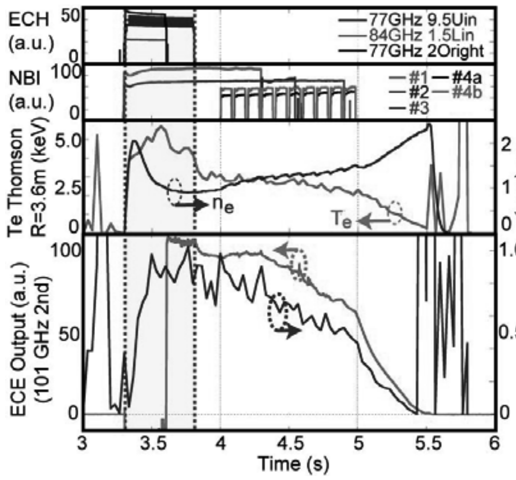

Fig.2 Typical example of ECE signal