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Innovative fast-scanning heterodyne receiver for Electron Cyclotron Emission measurements on HT-7 superconducting tokamak

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Abstract. Two sets of fast-scanning microwave heterodyne radiometer receiver systems employing Backward-wave Oscillators in 78-118GHz and 118-178GHz were developed for Electron Cyclotron Emission measurements (ECE) on HT-7 superconducting tokamak. The double-sideband radiometer in 78-118GHz measures 16 ECE frequency points with a scanning period of 0.65ms. The innovative design of a 2mm fast-scanning heterodyne radiometer in 118-178GHz enables the unique system to measure 48 ECE frequency points in 0.65ms periodically. Both overmoded transmission lines of horizontal midplane view of plasma in low field side and vertically viewing antenna paths with polarization selection capability of O mode and X mode were installed to study thermal and nonthermal ECE. Plasma profile consistency in reproducible ohmic plasmas were used to relatively calibrate each channels by changing toroidal magnetic field shot-by-shot, cross calibrations with Soft X ray Pulse Height Analysis measurements and 8-pulse 5-position Thomson Scattering system were made in a wide range of plasma parameters. Electron temperature profiles in confinement improved plasmas induced by pellet injection and in ICRF produced RF plasma were shown.

1. Introduction

Electron cyclotron emission (ECE) measurement has been an effective diagnostic tool to study electron temperature profiles and characteristics of nonthermal electrons, different types of frequency resolving receivers were developed to register ECE signals to meet a variety of physics interests due to the impractical realization of an ideal ECE receiver to meet all the requirements. Traditionally, people classify ECE receivers as optic system and microwave system. Michelson Interferometer, Grating Polychromator and Fabry-Perot inter-ferometer are optic systems; multichannel double-sideband (DSB) heterodyne radiometer with fixed frequency local oscillators, single-sideband (SSB) heterodyne radiometer with filter banks and fast-scanning heterodyne radiometer with backward-wave oscillator are typical microwave systems. Generally speaking, it is relatively easy for optic system to obtain capability to cover larger frequency range, while microwave heterodyne radiometers are able to achieve higher frequency resolution [1]. However, the recently developed ECE imaging techniques combines optic technology and microwave technology and reaches high performance [2]. The novel ECE system described in this paper organically integrates quasi-optic components and microwave components to make the fast scanning heterodyne radiometers achieve very good properties in ECE measurements on tokamaks [3,4].

2. Fast-scanning heterodyne receiver System for ECE in HT-7 tokamak

2.1 3mm fast-scanning heterodyne radiometer

A 3mm fast-scanning DSB (FSDSB) heterodyne radiometer with a backward-wave oscillator (BWO) in 78-118GHz was developed to measure temperature profile on HT-7 superconducting tokamak (R0=122cm, a=28cm, Bt: 1.5~2.2T) by second harmonic X mode ECE. Shown in Figure 1 is the block diagram of the receiver. Microwave power from BWO is directed to one arm of EH-T branch to mix with ECE or testing noise from the other arm by a broadband mixer in full band. The intermediate frequency (IF) of 100-500MHz is selected and amplified with gain of ~60dB, detected and processed with a 1MHz sampling rate to ensure fast scanning working mode. In contrast with the conventional structure of such heterodyne radiometer, the system sloughs off BWO power leveling loop [5] to decrease the flyback time of the receiver. When 16 work points are used, the fastest sweep time is 0.65ms, which means temperature profiles can be repeatedly measured every 0.65ms. Furthermore, in order to save lifetime of BWO, the scanning high voltage was applied to BWO only during plasma existence and was tuned off during the discharge interval.

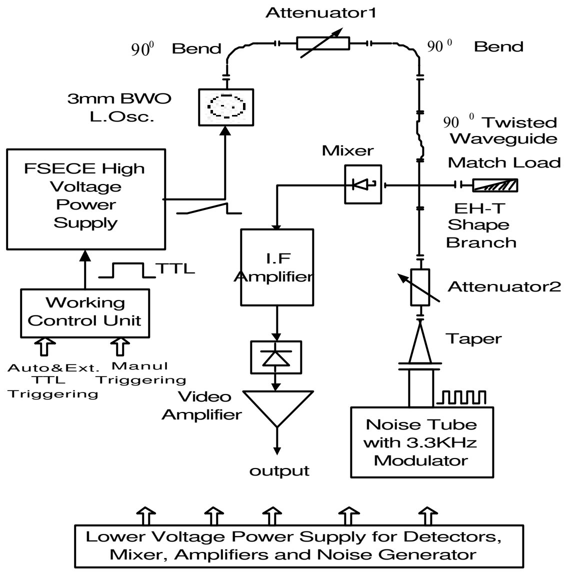

Figure 1. Schematic view of the 3mm fast-scanning DSB heterodyne receiver.

2.2 The 2mm novel fast-scanning heterodyne radiometer in HT-7

Conventional ECE heterodyne receivers utilize either double-sideband (DSB) narrow intermediate frequency band [5], or single upper sideband (SSB) with wide intermediate frequency band only [6]. In HT-7, ECE is required to measure electron temperature profiles in a wide range of operational regime and to study nonthermal ECE spectrum during current driving or heating plasmas. The ECE system should cover as wide frequency range as possi-ble with as many channels as possible within the frequency range, thus a novel heterodyne scheme to make use of all the DSB, USB and LSB at the same time around each local frequency points in a rapid scanning heterodyne receiver was proposed for HT-7 ECE system.

Maximum of 16 local oscillator (LO) frequency points in 118-178GHz were chosen according to the specific physics interests on HT-7 experiments. At each LO frequency, 0.1-0.5GHz IF frequency bands of DSB forms an independent channel of heterodyne receiver, USB frequency band forms another independent channel of receiver by down-converted mixing of ECE spectrum, LSB frequency band forms the third channel of radiometer by up-converted mixing of ECE spectrum. With total 16 LO frequency points chosen, total of 16×3 (Ch1, Ch2, Ch3)=48 measurable ECE frequency positions in a scan period are obtained. The quickest sweeping mode provides a 0.65ms scanning capability. Figure 2 shows the simple block diagram of the novel 2mm fast scanning heterodyne receiver. A complicated dual-beam interferometer (MP1) employing metal grid splitters was tuned to couple BWO power and reject noise spectra at USB and LSB, another interferometer (MP2) was tuned to separate USB ($f_{LO}+(1.5\pm0.5)GHz$) and LSB ($f_{LO}-(1.5\pm0.5)GHz$) from ECE spectrum and to suppress BWO noise power in these frequency ranges [7]. Local oscillator power from BWO and ECE from plasma were divided among the three broadband mixers by interferometers MP1, MP2 to form three independent channels, CH1, Ch2, CH3. Since this novel receiver system integrates DSB, SSB for USB and SSB for LSB mixing schemes in a one and works in a very fast scanning mode, it is named as FSDSSB heterodyne receiver in HT-7.

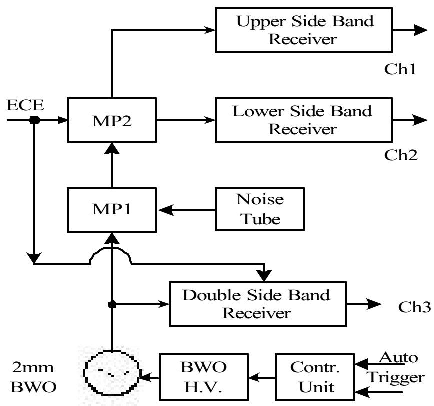

Figure 2. The simple block diagram for the novel 2mm fast scanning heterodyne receiver in HT-7 superconducting tokamak.

3. Set-up of FSECE and measurements in HT-7 experiments

3.1 Set-up of FSECE and Calibrations

The fast scanning ECE (FSECE) system in HT-7 is consisted of FSDSB, FSDSSB and transmission lines of ECE. Quasi-optic transmission lines were built to collect extraordinary mode and ordinary mode ECE in 78-178GHz from normal horizontal direction in low field side and from vertical viewing chords. Four X-band pyramid horns were put inside the necks of vacuum windows, the horns are 10cm from the edge of limiter plasma, two horns are for horizontal view and the other two are for vertically viewing ECE. Metal grids are used to select and purify ECE modes, X band waveguide is utilized to transmit ECE to receivers. Miter bends were used to change directions.

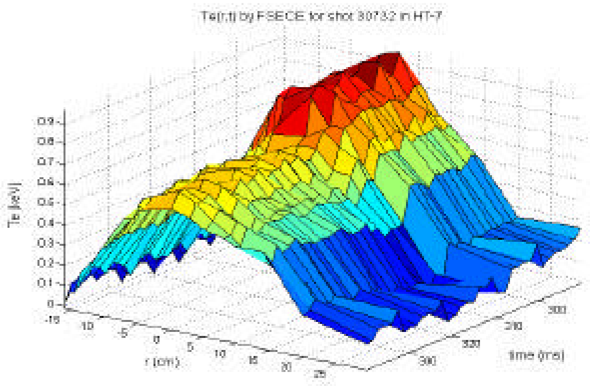

Figure 3 Te(r,t) of a pellet injection plasma in HT-7. H pellet was injected into plasma at 307.6 ms. Ip=150kA, Bt=1.81T.

Both 3mm and 2mm receivers and their transmission lines were calibrated. In a parameter window of MHD quiescent plasmas, several shots were measured by ECE system, the magnetic field varied a little in each shot to make a superposition for neighboring channels. In this way, relative calibration factors for each measurable ECE frequency points of the receivers were easily obtained, therefor the shape of electron temperature profile can be constructed. Absolute value of electron temperature is got by making comparison with the temperatures measured by soft X-ray pulse height analysis (SXPHA) and Thomson Scattering system in the same discharges.

3.2 Experiments

FSECE system is the only ECE system in HT-7 to provide conventional ECE measurements in HT-7. Figure 3 shows temporal evolution of electron temperature profiles during a pellet injection procedure. The time resolution of FSECE is 1.4ms. A small sized H pellet was injected into H plasma at 307.63 ms. The pellet ablated in the center of plasma causing central line averaged electron density increased from $1.24\times10^{13}cm^{-3}$ to $2.48\times10^{13}cm^{-3}$, central Te(0) decreased from 0.85keV to 0.6keV and the Te(r) profiles shrank. Some fluctuations were seen in the profile, they could be the result of sawteeth activity, since the time resolution of FSECE was set to 1.4ms and the sawteeth period is 3.9ms, the system can not follow the sawteeth variations precisely. Figure 4 shows the measured radiation temperature profile in an ion cyclotron range of frequency wave produced RF plasma, which was used in wall conditioning in HT-7, RF power was 50kW. The measured radiation temperature was about Trad~1.6-6eV.

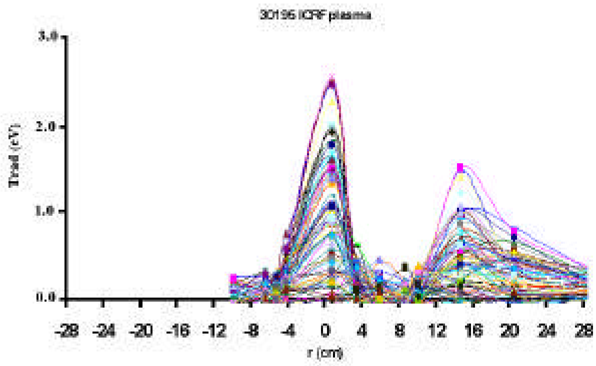

Fig.4 shows measured radiation temperature profiles in Ion Cyclotron Radio Frequency wave produced plasma. Working gas pressure is 6.4×10-4Pa, ICRF wave power is 50kW, Bt= 1.82Tesla, measured Trad is 1.6eV to 6eV.

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