

Preliminary Results from Electron Cyclotron Measurements at SST-1

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Abstract: An 8-channel heterodyne radiometer system is developed and installed for the measurements of second harmonic electron cyclotron emission (ECE) at magnetic field of 1.5 T at SST-1. This system covers a spectral range of 75.4 to 84.5 GHz at a spatial resolution of less than 1 cm, sensitivity of 9.51×10^6 V/W. The calculated noise temperature of the system is 1.66 eV. The system is calibrated using Hot/cold technique. This paper presents the preliminary observations of the heterodyne radiometer system at SST-1 and the measured radiation temperature.

1. Introduction

Electron Cyclotron emission (ECE) is a standard diagnostic in present day tokamak for plasma electron temperature measurements [1]. The use of multichannel super heterodyne receivers has made it possible to measure emission at high spatial and temporal resolutions. Since the ECE from optically thick plasma can be treated as blackbody radiation, the amplitude of ECE is proportional to the electron temperature. Furthermore, the frequency of the ECE is proportional to the magnetic field strength since the ECE is emitted due to gyro motion of electrons. In general, distribution of magnetic field strength in a torus experimental device is a function of radial position, and the radial temperature distribution can thus be measured by resolving the ECE signals with electron cyclotron frequency or its harmonics [2].

The present paper describes the design of the radiometer system for second harmonic temperature measurements for optically thick plasma at SST-1 at toroidal magnetic field of 1.5 T. The preliminary observation of the raw signal and comparison with SXR diagnostics is also described.

2. Experimental Setup

SST-1 is a medium sized fully super conducting tokamak with major and minor radius of 1.1 m and 0.20m respectively. The ECE frequency spectrum and corresponding optical thickness for SST-1 parameters having toroidal magnetic field $B_T = 1.5$ T, electron temperature $T_e = 300$ eV, and electron density $n_e = 2 \times 10^{19} \text{ m}^{-3}$ have been computed and shown in figure 1a and 1b. The optical thickness for X-mode emission ($n \geq 2$) can be computed as below

$$\tau_n^x = \frac{\pi^2 n^2 (n-1) R}{2^{(n-1)} (n-1)! \lambda} A_n \left(\frac{\omega_p}{\omega_c} \right)^2 \left(\frac{k_B T_e}{m_e c^2} \right)^{n-1} \quad (1)$$



where R is the major radius and the factor A_n is a constant calculated in Born [3]. For a tenuous plasma the constant A_n is approximately 1. From the graph it can be seen that 2nd harmonic ECE frequency (f_{ce2}) spectrum ranges from 72 GHz to 102 GHz, for which, the plasma is optically thick and favorable for electron temperature measurements. In our initial design we are covering only half of the entire plasma cross section with 75.4 GHz - 84.5 GHz, frequency range that lies on the low field side. However, we are working on the process of designing a radiometer that would also be covering the other side i.e. high field side of the SST-1 plasma cross section. Henceforth we would be able to resolve the plasma electron temperature on high field side as well as low field side.

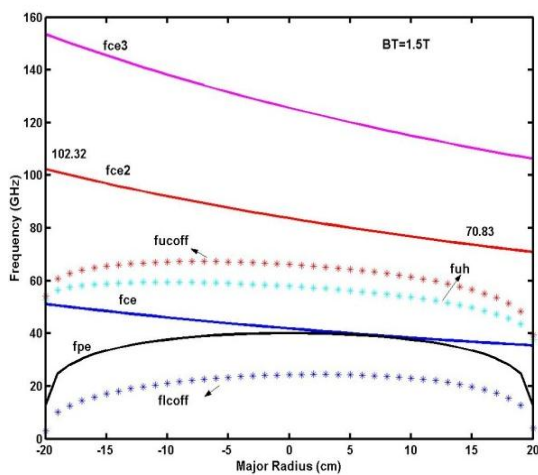


Figure 1a. Frequency plot for SST-1 at $B_T = 1.5$ T

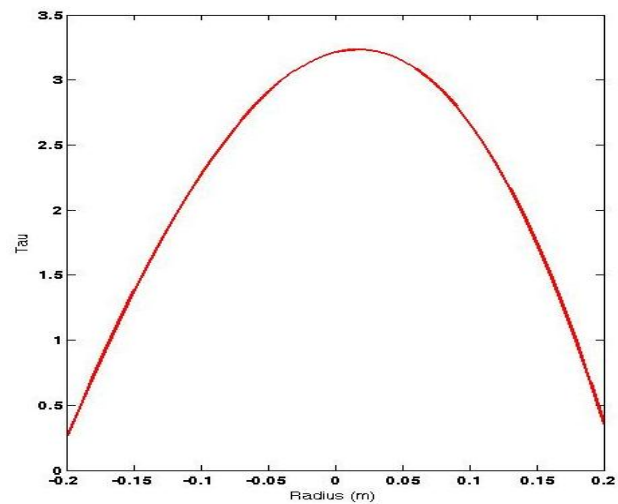


Figure 1b. Optical Thickness at $B_T = 1.5$ T

2.1. Radiometer system - Design

The designed E-Band Radiometer system, as shown in figure 2, is a heterodyne system with an input RF of 74-86 GHz down-converted to an IF of 1-12 GHz. Further the electronics amplifiers and data acquisition system are used for data sampling and filtering.

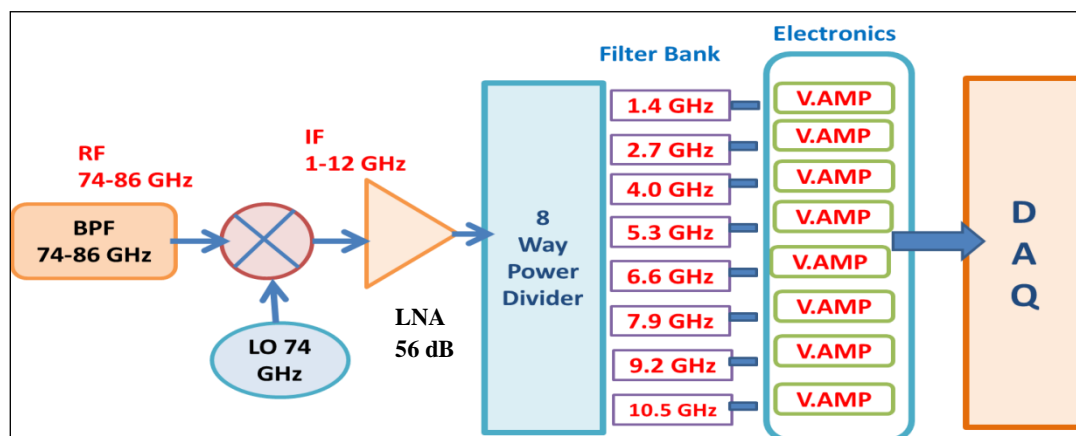


Figure 2. Block diagram of the designed radiometer system.

The EC emission is collected by a horn Antenna with gain of 23 dBi and transmitted by an oversized waveguide (X-Band) to the diagnostics room that is situated at a distance of 9.5 m from the tokamak machine. The emission that reaches the front end of the radiometer system is passed through

a band pass filter allowing a spectrum of 74-86 GHz only. The filtered radiation is passed on to the down converting unit which consists of a balanced mixer and a fixed frequency local oscillator at 74 GHz, translating the RF spectrum to an IF spectrum of 1- 12 GHz.

The IF of 1-12 GHz is further amplified using Low Noise amplifiers with a total gain of 56 dB. This amplified signal is split into 8 channels using an 8-way power divider. Frequency selective cavity filters at frequencies 1.4 GHz to 10.5 GHz, with a step size of 1.3 GHz and a bandwidth of 400 MHz, follows each channel of the power divider. The signal is detected using a zero bias Schottky detector.

Electronic modules follow the voltage output of the detectors for signal conditioning and filtering. The electronic modules are divided into 3 parts: (1) A signal conditioning system (2) Two stage amplification (3) Filtering and optical isolation. The signal from the electronic modules is differentially carried to the DAQ system using a Multicore cable.

The calculated spatial resolution of the system is 0.65 cm while its temporal resolution is 1ms. This will be enhanced further. The calculated system noise temperature is of 1.66 eV that depends on the overall noise figure of the cascaded components of the system.

3. Calibration

In order to obtain the electron temperature from ECE measurements the receiver system has to be calibrated. The ideal way to calibrate the radiometer system would be to use a black body at the temperature close to the plasma temperature. Unfortunately, such black bodies with such high and known temperatures do not exist.

We have developed a silicon carbide based black body source that can withstand a temperature of 800 °C and is used for the calibration of the radiometer system. This black body at 600 °C acts as the hot body while the room temperature acts as the cold body source. An in situ arrangement for calibration is required to avoid any kind of errors during plasma electron temperature measurement. However, such an in situ kind of calibration is not possible here now, so the system is calibrated in lab including the transmission line losses; window losses and free space propagation losses that are calculated experimentally. The Y-factor so obtained by the calibration process is used to determine the plasma electron temperature.

4. Experimental Results

The radiometer system is horizontally aligned to a quartz window that receives the ECE radiation in the E-band. The system measures a part of the second harmonic i.e. 75.4 to 84.5 GHz on the low field side covering a radial location from - 1.02 cm to 12.13 cm. Figure 3 below shows the raw data received by the radiometer system for one of the SST-1 discharges.

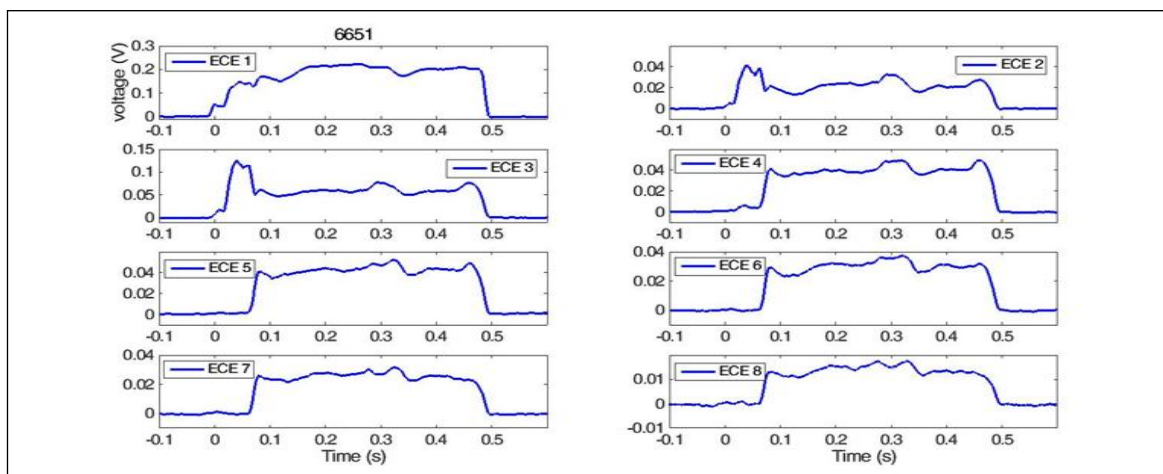


Figure.3 Raw data from ECE radiometer wherein ECE 1 to ECE 8 corresponds to radial locations 12.13cm, 10.06 cm, 8.06 cm, 6.13cm, 4.24 cm, 2.44 cm, 0.68 cm, - 1.02 cm respectively.

The depicted raw data is converted to plasma temperature using the calibration factor as described in section 2.2. The temporal and radial evolution of the measured radiation temperature, through ECE radiometer, for shot 7030 are shown in the figures below.

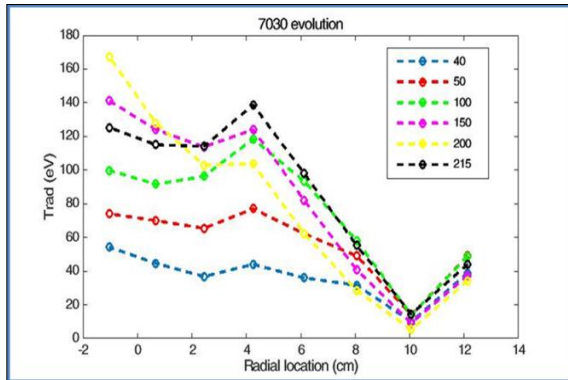


Figure 4a. Temporal evolution of T_{rad} .

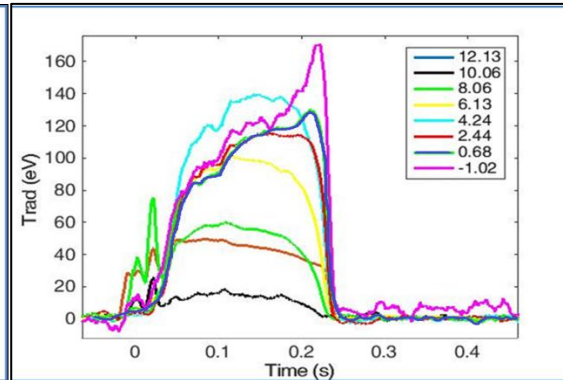


Figure 4b. Radial evolution of T_{rad} .

Since the measured density and temperature are of the order of $1 \times 10^{13} \text{ cm}^{-3}$ and 200 eV, this plasma does not satisfy the optical thickness conditions for electron temperature measurements using ECE Radiometer system. Hence the measured temperature, as given by the ECE measurements, is the radiation temperature.

The comparison of the radiation temperature so measured is done with another temperature measuring diagnostics i.e. SXR that is available at SST-1. SXR diagnostic is designed to measure the chord averaged electron temperature of the central plasma region using the absorption foil thickness principle. Figure 5b shows the trace of the temperature data obtained by SXR diagnostic within an error of 30 %. The results measured by both the diagnostics are shown in figure 5a and 5b for one of the discharges at SST-1. However in most of the discharges the ECE measured temperature is found higher than that measured by SXR. Analysis is being carried out in this regard.

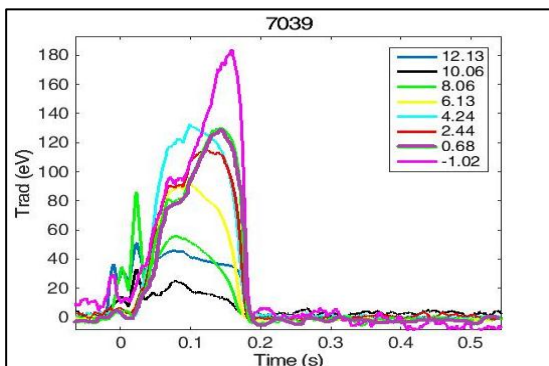


Figure 5a. T_{rad} measured by ECE radiometer.

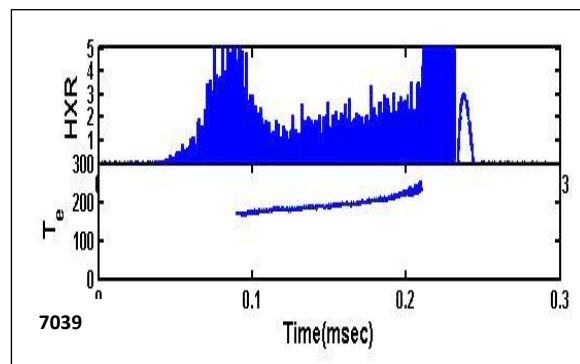


Figure 5b. T_e measured by SXR diagnostics.

5. Conclusion

An 8-channel heterodyne ECE radiometer is installed at SST-1 for temperature measurements. The design and calibration process for the diagnostic is explained. The observations and the measured radiation temperature are also shown with relevant comparison with SXR diagnostics. The measured radiation temperature using ECE diagnostics is around 180-200 eV.

References

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