PRELIMINARY RESULTS OF PROTOTYPE MARTIN-PUPLETT INTERFEROMETER AND TRANSMISSION LINE DEVELOPED FOR ITER ECE DIAGNOSTIC

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Abstract

The Electron Cyclotron Emission (ECE) Diagnostic system in ITER will be used to determine the electron temperature profile evolution, the high frequency fluctuation of the plasma electron temperature, the characterization of runaway electrons and the radiated power in the electron cyclotron frequency range (70-1000 GHz). These measurements will be used for advanced real time plasma control (e.g. steering the electron cyclotron heating beams) and the ITER plasma physics studies. An ultra-wide band (70 – 1000 GHz) transmission line coupled to a fast scanning and broadband spectrometer is required to estimate the ECE radiated power loss and to study the behavior of runaway electrons in the ITER plasma. Typically, the transmission line and spectrometer are not operated under vacuum and there are consequently significant losses due to water vapor line and continuum absorption over this large frequency range. To avoid these losses, both the transmission line and the spectrometer must be operated in vacuum. Designing an efficient, high etendue long wavelength spectrometer with extremely high scan speeds in vacuum is a major challenge. For the transmission line development, the challenges lie with the large lengths involved (~ 43 meters), ultra-wide frequency range required, and low calibration source power (~ nW level) available. A test facility has been established at the ITER-India laboratory to evaluate the performance of various prototype subsystems of the ECE diagnostic. The facility consists of a high temperature black body source covering the frequency range 70-1000 GHz, a transmission line, and a Fourier Transform Spectrometer (FTS) of the Martin-Puplett Interferometer (MPI) configuration. The MPI operates under vacuum, has high throughput, excellent time resolution of 10 ms, and a scan displacement of 15 mm. In this paper, we present preliminary results of the efficiency of a transmission line obtained with the prototype MPI. While the transmission line is designed to be operated under vacuum, it was not evacuated for these preliminary tests.

1. INTRODUCTION

The Electron Cyclotron Emission (ECE) diagnostic system [1] on ITER will be used to determine the electron temperature profile evolution, the electron temperature fluctuations, the runaway electron spectrum, and the radiated power in the electron cyclotron frequency range (70-1000 GHz). These measurements will be used for advanced real time plasma control (e.g. steering the electron cyclotron heating beams), and fundamental physics studies.

Determination of the radiated power loss in the ECE frequency range of 70 to 1000 GHz requires a transmission line to convey the radiation to an ultra-wide band spectrometer. There are many water vapor lines within this ultra-wide band which absorb a significant amount of radiation, not only at or near the line centers, but also in the extended wings of the lines which produce an effective continuum absorption; for this reason the transmission line and the spectrometer must be evacuated. The key challenges are: i) to design an efficient, high etendue long wavelength spectrometer with extremely high scan speeds that operates under vacuum; and ii) to design efficient, wide band, long and evacuated transmission lines. The key goal is then to calibrate the total system (i.e., the end-to-end efficiency of the transmission line and spectrometer). In this paper, we describe the experimental set up and present preliminary results of transmission line attenuation measurements obtained with the rapid scanning FTS.

2. DETAILS OF THE FTS AND TRANSMISSION LINE

A rapid scanning FTS covering the spectral range from 70 – 1000 GHz for ECE diagnostic applications has been designed and developed [2]. The FTS is of the Martin-Puplett Interferometer (MPI) configuration [3]. The MPI operates under vacuum, has high throughput, excellent time resolution of 10 ms, and a scan displacement of 15 mm that provides a spectral resolution better than 10 GHz and detectable power measurement dynamic range of 29 dB with detector noise equivalent power (NEP) of $\leq 2 \times 10^{-12}$ W/Hz$^{1/2}$. An image of the spectrometer system is depicted in Fig 1. The system consists of four main parts: (1) Gaussian Beam Telescope feed optics; (2) Interferometer and moving mirror scanning engine; (3) Cryogenic detector system; and (4) Data acquisition and control system. The first two parts are enclosed in the large vacuum chamber shown in Figure 1. The two inputs to the spectrometer are shown in Fig 2. Either one of the inputs can be used for the measurement of the radiation, typically the other input is used as a reference. The stability of the FTS is such that there is less than a 1% variation in intensity between the first and last spectrum taken over a continuous period of more than sixteen hours of operation.

The transmission line consists of straight waveguide sections of 2 meters in length, pump out tee, miter bends, and vacuum joints. These components are smooth walled circular waveguides with inner diameter of 72 mm and outer diameter of 88 mm. The inner surface finishing of the waveguide components is 7.5 micron Ra to enhance the performance of the transmission line. A blackbody millimetre wave source has also been designed and developed [4]. Details about the source are presented in a companion conference paper # FIP/P1-32.

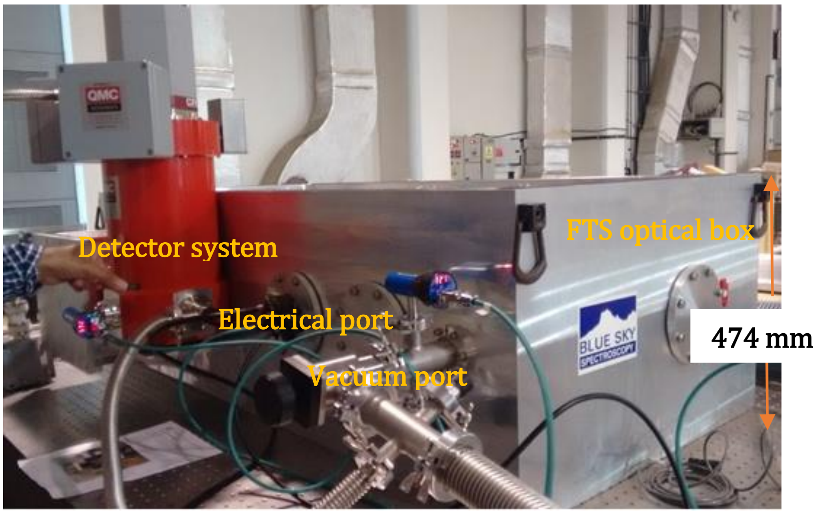

FIG.1. Photograph of the ECE spectrometer identifying key components

3. EXPERIMENTAL SET UP AND PRELIMINARY RESULTS

In this section, the description of measurement of the various parameters of the FTS and the transmission line are given along with the experimental set up.

3.1 Testing of FTS Parameters

The key FTS parameters (spectral range, frequency and temporal resolution, stability, etc.) were measured during installation of the interferometer at ITER-India lab. The experimental set-up for these measurements is shown in the Fig 2.

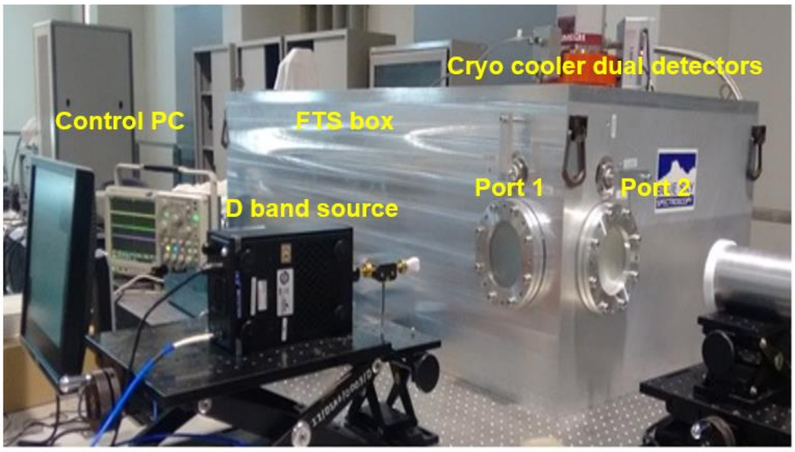

FIG. 2. Photograph of the ECE spectrometer showing sources and inputs

An example of a spectrum produced by the FTS when viewing a blackbody source is shown in Fi 3. The spectrum is measured over the range from 100 GHz to 1 THz, which meets the ITER requirement. Since the calibration source is not under vacuum, water vapour absorption lines are observed in the spectrum.

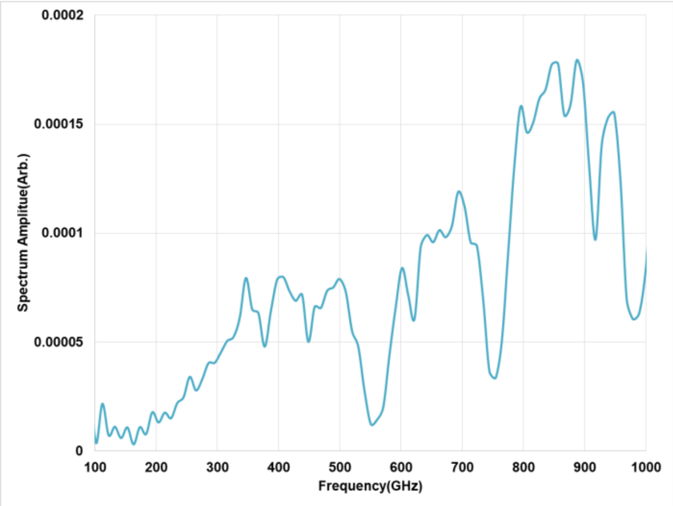

FIG.3. the spectrum profile of the liquid nitrogen temperature black body source

The frequency resolution of the spectrometer is determined using a low power mm wave D-band source (110-170 GHz) operated at 140 GHz (shown in Fig 2). A total of 30200 interferograms, sampled for every 24.8 μm path difference, were measured and averaged. The spectral resolution can be determined from the optical path difference (OPD) range of the interferogram. The signal near the position of zero path difference show the broad-band continuum superimposed on the 140 GHz signal. The spectrum of 140 GHz line source is shown in Fig 4.

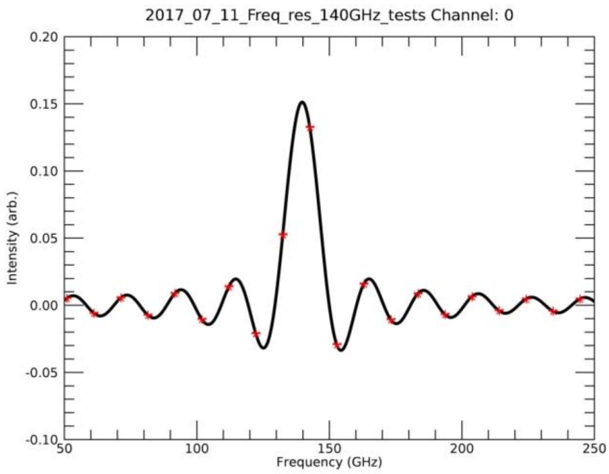

FIG.4. Phase corrected (red symbols) and zero-padded spectrum (black) of the 140 GHz line source showing classical sinc instrumental line shape.

The stability of the interferometer measurement is derived by taking the ratio of the phase corrected spectra observed at t=19 hours to that observed at t=0 hours. This is shown in Fig 5. The stability is approximately 1% as per requirement. The deviation in the stability is primarily due to the variation in water vapour along the line of sight.

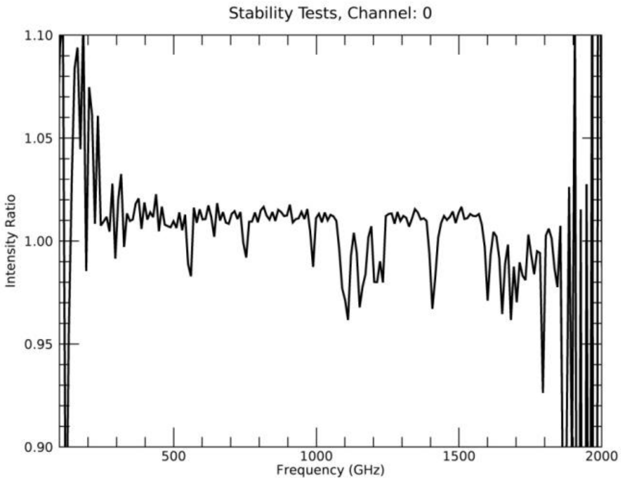

FIG.5. the stability of the FTS expressed as the ratio of spectra taken 19 hours apart. Large variations correlate with the position of water vapour lines indicating that environmental effects dominate the current stability measurements

3.2 Transmission line

The experimental set up for the transmission line attenuation measurement consists of the blackbody radiation source, the transmission line and, the FTS. Fig 6 shows the measurement set up of 10 meters length transmission line with three miter bends. The black body source is a microwave absorber made of Eccosorb immersed in liquid nitrogen.

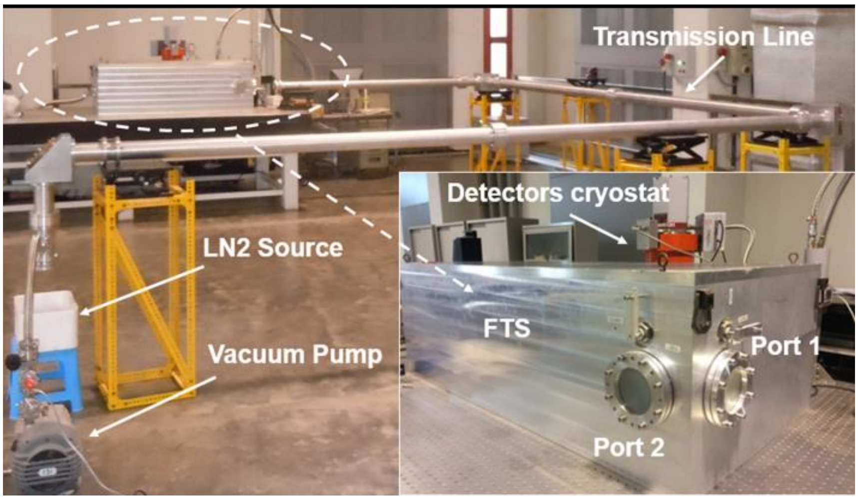

FIG.6. Experimental configuration for the transmission line attenuation measurement

The spectrometer was operated at a resonant frequency of 50 Hz for 300 seconds producing 30000 interferograms. Each interferogram consists of detector voltage recorded as a function of the optical path difference between the two beams of the interferometer. The data reduction software computes the average interferogram which is subsequently Fourier transformed to produce the corresponding spectrum (e.g, Figure 3). In principle, spectra obtained using transmission lines of different lengths can be used to determine transmission line losses using cut back method [5]. However, when the transmission lines are not evacuated additional losses due to atmospheric absorption occur which cannot be separated from those associated with the transmission lines themselves.

Although we were not able to evacuate the transmission lines in these preliminary measurements, we have used our atmospheric modelling software, BTRAM [6], and a simple radiative transfer model to simulate the effects of atmospheric absorption. In this model, the laboratory was assumed to have an air temperature of 298 K with a relative humidity of 40%, with blackbody sources of temperature 77 K and 298 K placed at port 1 and port 2, respectively. The results are shown in Fig7 for two transmission lines of length 2 m and 10 m, respectively, with a total additional air path of 0.5 m between the source/FTS and transmission lines. Although this analysis should be treated with caution and not over-interpreted, there is seen to be very good agreement both in the width of the water vapor lines and the continuum, which supports the thesis that the atmosphere is playing a significant role.

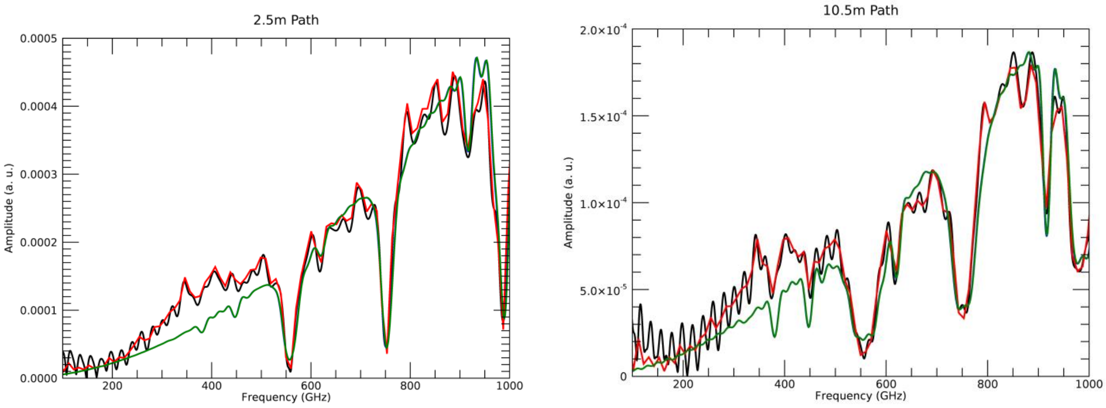

FIG.7. Comparison of measured (red) and simulated (green) spectra for total paths of 2.5 m (left) and 10.5 m (right).

4. CONCLUSION

This paper describes the methodology for evaluating the performance of various subsystems of the ITER ECE diagnostic. The preliminary results obtained with the FTS of transmission line components developed for the ITER ECE diagnostic have been presented. The key parameters of the rapid scanning FTS have been verified during the installation and commissioning phase. While it has not been possible to determine precisely the efficiency of the smooth walled circular waveguide due to the effects of atmospheric absorption, the measured spectra have been shown to be well described by a simple radiative transfer model. The results provide confidence that once the transmission lines are evacuated; the FTS will serve as a powerful diagnostic for spectral measurements of the transmission lines and components including the polarizer splitter unit.

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