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GENERAL OVERVIEW OF THE ITER LOW FIELD SIDE REFLECTOMETER DIAGNOSTIC SYSTEM*

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ABSTRACT

The Low-Field- Side (LFS) Reflectometer is one of several reflectometer systems planned for ITER. The LFS Reflectometer microwaves reflecting off the O and X-mode cutoffs in the plasma, are used to probe the on and off-axis edge pedestal and scrape-off layer (SOL) electron density (n_e) profiles. The LFS reflectometer will also be used for core MHD and turbulence measurements on ITER. The LFS system includes the antenna and transmission line for a Doppler reflectometer for turbulence rotation measurements. The front-end components of the LFS Reflectometer are housed in an equatorial port plug. The current LFS Reflectometer design contains 7 circular waveguides that function as both launch and receive antennas, with penetrations through the diagnostic first wall providing access to the plasma. The millimeter waves are coupled quasi-optically to the corresponding waveguides outside the vacuum through double quartz windows and quasi-optical Gaussian telescopes. The reference design features 7 broadband multimode corrugated circular waveguide transmission lines. The total length of the waveguide run from launch/receive horn to source/detector is approximately 40 meters. Details of the current mechanical, thermal and instrumentation design of the diagnostics system will be presented in this paper.

Key Words: ITER, Microwave Diagnostics, Reflectometry

1- INTRODUCTION

One of the diagnostic systems being provided to ITER by the US is the Low-Field-Side (LFS) Reflectometer. The LFS Reflectometer is one of several reflectometer systems planned for ITER. The LFS Reflectometer microwaves in the range of 50 GHz-165 GHz reflecting off the X-mode and O-mode cutoffs in the plasma, are used to probe the on and off-axis edge pedestal and scrape-off layer (SOL) electron density (n_e) profiles. While the main function of this diagnostic is the measurement of the electron density (n_e) profile, it will also be used for core MHD and turbulence measurements. In addition the LFS system includes a Doppler reflectometer with oblique views to the plasma flux surface, for turbulence rotation measurements.

The ‘front-end’ components of the LFS Reflectometer are housed in the equatorial port plug number 11 (EPP-11) being designed and built by the Russian Federation. The LFS reflectometer components share this plug with four other diagnostics. The current LFS Reflectometer (LFSR) design consists of 7 circular waveguides that function as both launch and receive antennas, with penetrations through the diagnostic first wall providing access to the plasma. The millimeter waves are coupled quasi-optically to the corresponding waveguides outside the vacuum through double quartz windows. The reference design features 7 broadband multimode corrugated circular waveguide transmission lines. There are multiple miter-bends in the transmission lines as they take the signals to and from the diagnostic hall to the machine. The total length of the waveguide run from launch/receive horn to source/detector is approximately 40 meters. Engineering a microwave diagnostic for ITER nuclear and thermal expansion environments present many design challenges which are presented here with solutions designed to address them. Section 2 of this paper describes the design and integration of in-vessel front end LFSR components into the diagnostic shield module (DSM) and the port plug. Section 3 is a description of the design of the ex-vessel transmission line (Including the quasi-optical Gaussian telescope) in ITER interspace, port cell, and gallery areas. Section 4 describes the LFSR instrumentation and multiplexing to the transmission lines.

2- IN-VESSEL COMPONENTS AND DESIGN

The LFSR antennas are basically waveguide antennas. There are of the same design as the waveguides that make up the transmission line (i.e. corrugated over-moded circular 63.5 mm id). They are designed to be flush with the diagnostic first wall (DFW). These seven antennas are shown on Figure 1 and 2. The single waveguide antenna at the top is the Doppler back-scattering reflectometer antenna. The 2x3 midplane array of antennas below are designed to accommodate different plasma heights for the profile and MHD/turbulence reflectometers. The antennas both send the reflectometer microwaves toward the plasma and collect the reflected waves back from the plasma (i.e. bistatic fashion).

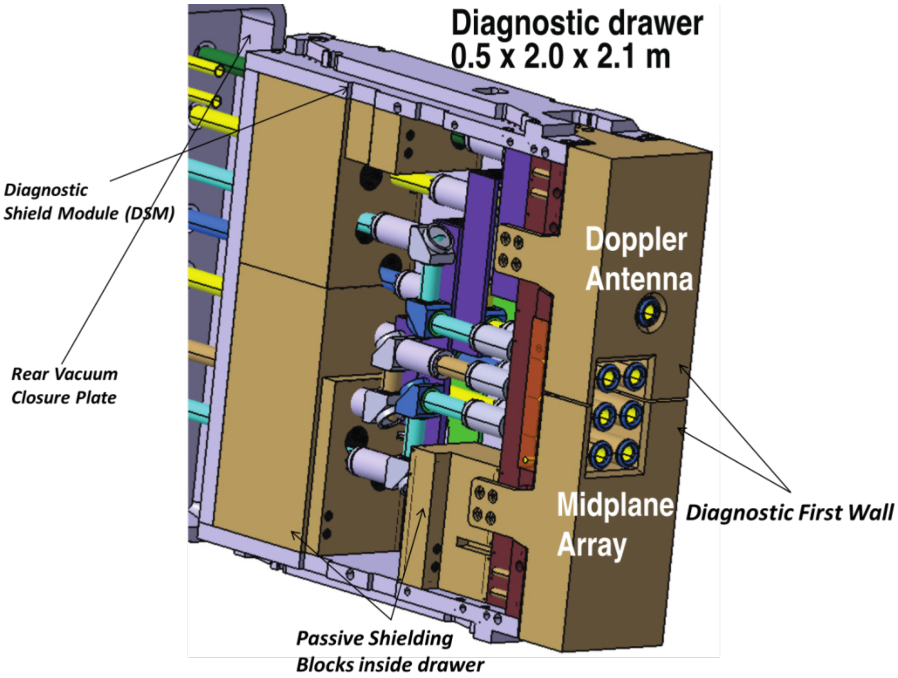

Figure 1: The in-vessel components of LFSR inside the DSM

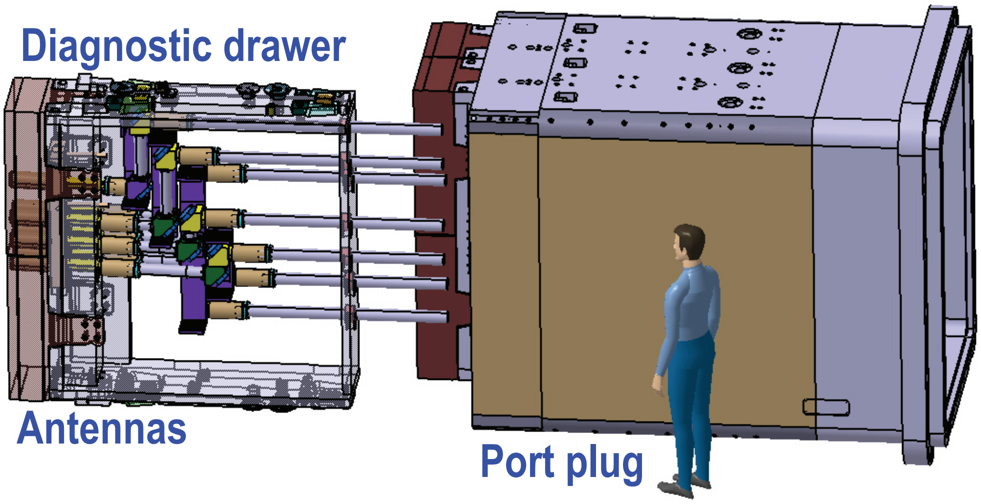

Figure 2: DSM 1 in the equatorial port plug number 11

Because these waveguide antennas directly face the plasma, they must withstand the heating from the ITER plasma bremsstrahlung radiation and neutrons from the D-T reactions. For this reason a cooling jacket is designed to provide cooling water to continuously cool the tip and body of the 7 stainless steel (316-LN) waveguide antennas. Since a relatively large section of DFW is taken away to make room for the antennas, the neutrons can stream in to the front plate of the diagnostic shield module (DSM). Therefore the antenna mounting plate needs to be cooled as well. Figure 3 shows the antenna and mounting plate cooling arrangement. The cooling water enters the cooling paths gun-drilled into the mounting plate at the top and all 7 antennas sequentially, starting from the top single Doppler antenna and the 2x3 midplane array antennas. At each antenna cooling jacket the specially designed ribs direct the cooling fluid to the tip of the antennas (where most efficient cooling is needed) and back to the base.

Afterwards the water takes a path inside the plate in the labyrinths designed to cool the areas of the mounting plate between the antenna attachments.

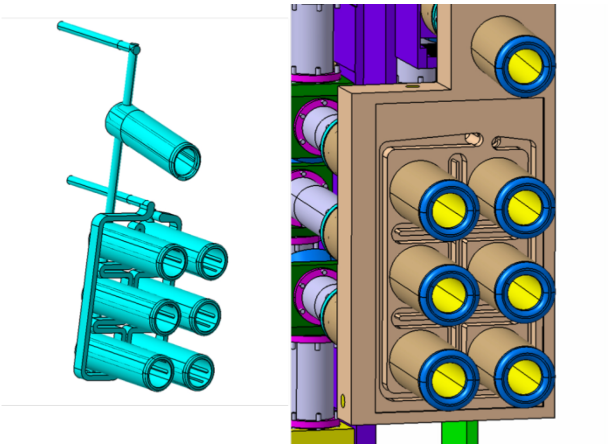

Figure 3: Front end antenna cooling arrangement. The picture on the left shows the water volume.

The LFSR antennas join the rest of the transmission line by waveguide extensions to a pair of miter bends designed to provide dog-leg offsets to limit neutron streaming to the back of the DSM. Figure 1 shows this setup. Boxes of Boron Carbide will be placed passed the miter bends as passive shielding blocks to capture the fast neutrons and lower the dose rate in the back of the DSM and port plug closure plate.

After the second miter bend straight waveguides direct the waves to the back of the\\he port plug where the waveguides stop short of the ITER double windows. The waves are coupled quasi-optically across the windows to the ex-vessel waveguides. This design allows the ex-vessel transmission line to be open to air and not carry the machine vacuum for any length. This is a very important design advantage as the ITER begins Tritium operation. In addition this allows us to use standard ITER vacuum windows.

3-EX-VESSEL TRANSMISSION LINE

The ITER vacuum vessel is heated to 100 C during operation and 200 C during bake-out, while the LFSR and other diagnostics components are installed in the ITER interspace (IS) frame at room temperature. The resulting thermal expansion (up, radially outward and phi-twist) and the build variation resulting from the IS structure being built on a different building from the building the ITER vacuum vessel is attached to, call for a design that allows the ex-vessel transmission line to align to the vessel at operating temperature while withstanding the bake-out temperature expansion.

This is achieved in LFSR through design of a quasi-optical telescope with a moving mirror arrangement to keep the in-vessel waveguide imaged through the vacuum window onto the ex-vessel waveguide. This quasi-optical telescope is shown in Figure 5.

Although in the port plug, LFSR is the only diagnostic in the first of 3 DSMs, the rest of the LFSR interspace transmission line is supported in the interspace frame along with ex-vessel components of other equatorial port plug #11 (EPP11) tenant diagnostics. The waveguide route goes to the ceiling level after going through the ITER bio-shield and stays on the ceiling supported by frames hung from the ceiling embedments. Multiple miter bends, one set of which is out of plane keep the waveguide routed through the port cell and gallery. The waveguides go above the door between the port cell and the gallery and emerge through a penetration (yet to be designed) into the LFSR room in the diagnostic hall.

4-REFLECTOMETER INSTRUMENTATION

The LFSR instrumentations are 3 frequency-modulated continuous wave (FMCW) bistatic source/receiver reflectometer systems: 2 X-mode systems to cover the full-field and halffield ITER operations at 110-165 GHz and 50-110 GHz respectively, and an O-mode system in the frequency range of 50-110 GHZ. The Doppler instrument will be provided in later phases of the project. Depending on the toroidal field and position of the plasma and the desired measurement te three instruments will be multiplexed into the 6-waveguides that are connected to the 2x3 array of profile reflectometry antennas. These multiplexing fast waveguide switches are currently being designed.

The FMCW instruments has the source and receiver connected to the same bistatic (send and receive) waveguide. There are more than 80 meters of waveguide and over 20 miter bends in the roundtrip signal travel from the source/receiver to the antenna. The losses in the signal plus the large plasma ECE background require a strong wideband source in the instrument. This source ******[1,2] was specifically designed and manufactured for the LFSR by Virginia Diodes, Inc. (VDI), under separate SBIR funding. The original key design parameters for the source were a target power output of 100 mW (20 dBm) across the entire 50-165 GHz frequency range, and a fast full band frequency sweep capability (i.e. full band sweep time as short as 1 u*******s). The source includes hardware in three separate bands, specifically V-band (50-75 GHz), W-band (75-110 GHz), and D-band (110-165 GHz), integrated on a single optical plate, along with a beam combining system, as shown in Figure 6. In the photograph, the V-band subsystem begins at the bottom middle, the W-band system is located at the upper left, while D-band is at the lower right. The outputs from the three microwave bands are frequency combined a quasi-optical system of mirrors and frequency selective surfaces (FSS), which act as frequency filters. These quasi-optical components are visible in Figure 6(a), while the beam paths in the multiplexer system are illustrated in different colors in Figure 6(b). The quasi-optical beam multiplexing system was designed and constructed by Thomas Keating Ltd. of the UK, for VDI. Figure 7 shows the output of the combined system across the frequency range of interest.

5-CINCLUSIONS

The ITER low Field side reflectometer is being designed by US-ITER (i.e. Princeton Plasma Physics Laboratory). The diagnostic is in the preliminary design phase. Many design innovations described in this paper had to be devised to accommodate the unique nuclear, radiation, and operating temperature requirements and size of ITER. T

he LFSR diagnostic, when fully deployed, will be able to provide the on and off-axis edge pedestal and scrape-off layer (SOL) electron density (n_e) profiles. In this capacity it plays an important machine protection role. While the main function of this diagnostic is the measurement of the electron density (n_e) profile, it will also be used for physics purposes such as core MHD and turbulence measurements. In addition the LFS system is equipped with the antenna and transmission line for a Doppler reflectometer with oblique views to the plasma flux surface, for future turbulence rotation measurements.

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