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The Use of DIII-D as a Testbed for ITER ECH Transmission Line Components

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Abstract. The operational experience of present day high power EC systems is nominally only for a few seconds. This is a long way away from the thousands of seconds required for ITER. It would be beneficial to the ITER program that EC system components be tested to full parameters prior to committing to producing the full set of components. The planned growth in the EC system on DIII-D over the next few years provides the opportunity to assemble a test stand for ITER EC components. By building the DIII-D hardware to the ITER specifications it will allow ITER to gain beneficial prototyping experience on a working tokamak, prior to committing to building the hardware for delivery to ITER.

1. Introduction

The ITER EC system will consist of twenty-four 170 GHz 1 MW, (or possibly 2 MW) gyrotrons and three 120 GHz 1 MW startup gyrotrons connected to twenty-four 63.5 mm diameter corrugated evacuated low loss transmission lines. By a combination of in-line waveguide switches the gyrotrons can be connected to either the midplane launcher or to a set of three upper-plane launchers. The layout of the ITER EC system is shown in Fig. 1. The ITER EC system will expand the present day experience of EC transmission lines by operating for a nominal pulse length of 400 seconds, and possibly as long as 3600 seconds, which is more than forty to several thousand times longer than present day systems. And at the 2 MW level, this will place a higher power level on transmission lines than has been previously experienced.

To connect the microwave power generated in the gyrotrons to the launchers of ITER the rf beam exiting the gyrotron must be coupled into a low loss transmission line. This is achieved at a rf conditioning unit, which uses a single or a set of mirrors to focus and /or condition the output beam into the entrance to the waveguide, where it is propagated at a low loss in the $HE_{1,1}$ mode. Since there is some level of stray radiation exiting from the gyrotron the rf conditioning unit must also incorporate an absorber to capture this radiation. The waveguide chosen for ITER is 63.5 mm in diameter, with corrugations to allow transmission at a relatively low loss of 0.02 dB/100 m (0.5%/100 m). To prevent breakdown inside the waveguide, the waveguide is evacuated to a pressure below 10^{-5} Torr. The anticipated loss is so low that for one or two MW of transmitted power, even at a continuous level (cw), the waveguides will not over heat and can be cooled using normal convection means.

However, since the location of the gyrotrons with respect to the launchers is not a straight line of sight, the transmission line must incorporate several bends to create a reasonable path from the gyrotron hall to the torus. Simple 90 deg. miter bends are used to make the transition of the waveguide

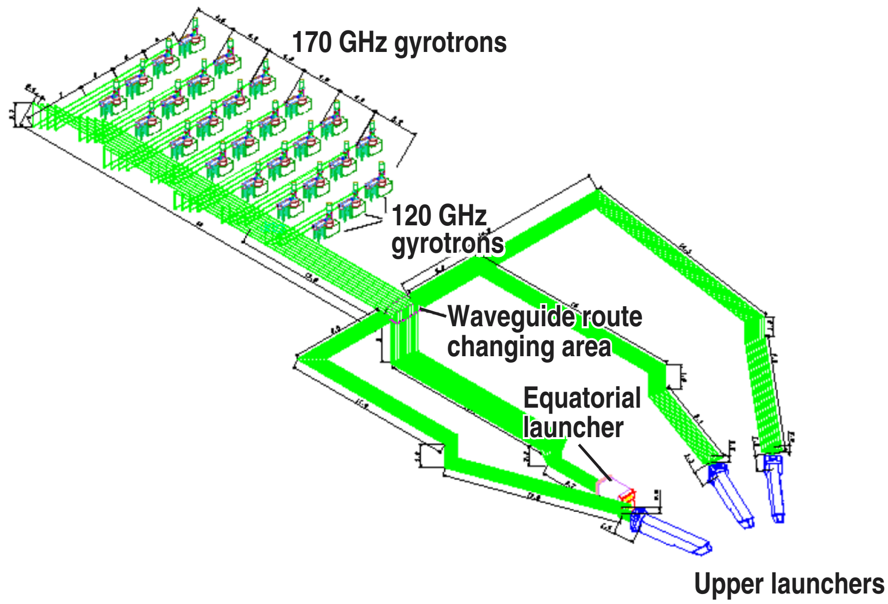

Fig. 1. A layout view of the ITER EC system.

from one direction to another. However the nature of miter bends is that in order to match the boundary conditions at the miter mirror surface, the $HE_{1,1}$ mode is decomposed into several other lower order modes. These lower order modes do not have as low a propagation value as the $HE_{1,1}$ mode, and the energy in these modes will be dissipated in the waveguide a few meters down stream from the bend. A phase corrected mirror can be used to minimize the mode conversion, but it is still anticipated that the mode conversion at each miter bend will be 0.01 dB (0.2%), which could lead to excessive temperatures in or near the miter bend, and this in turn could lead to a local rise in waveguide pressure causing a catastrophic plasma breakdown within the waveguide. In addition to the mode conversion losses there are also ohmic losses on the miter mirrors and appropriate cooling means must be used to limit the temperature rise of the mirrors and waveguides.

The miter bends offer the opportunity to perform several other functions that are needed to transmit the rf power to the launchers, some of the mirrors are grooved and rotatable to allow for polarization control, some mirrors have small coupling holes to monitor power levels or look for arcs, and some have moving mirrors so that the rf beam can be redirected into a different direction (waveguide switch). Each of these components adds an additional level of thermal management issues that must be addressed.

In addition to miter bends there are other waveguide components that are required to complete the ITER transmission line system, these are bellow sections, dc breaks, pumpout sections, gate valves, mode filters, thermal expansion joints, and dummy loads. Other than the dummy loads, these other components should not have extreme thermal management issues, but they need to be evaluated and validated before they are used on ITER. A list of the individual waveguide components needed for ITER is given in Table I.

2. DIII-D ECH System

The DIII-D ECH system is very similar to the one envisioned for ITER [1]. It consists of MW class 110 GHz gyrotrons connected to a low loss corrugated evacuated waveguide, which has many of the waveguide components anticipated to be used on ITER. There is a single mirror rf conditioning unit, 31.75 mm diameter corrugated evacuated waveguide, directional couplers, polarizing miter bends, pumpout sections, dc breaks, waveguide switches, gate valves and dummy loads. Because the pulse length of DIII-D is 10 seconds or less the thermal management issues with the components are not severe and thus smaller diameter waveguides could be used, and the only active cooling required is for the miter bend mirrors. The DIII-D EC System is shown in Fig. 2.

Table I. ITER Waveguide Components

Item	Quantity (typical)
RF conditioning unit for 170 GHz	24
RF conditioning unit for 120 GHz	3
62.5 mm corrugated waveguide	2000 m
Miter bends	24
Directional couplers	51
Polarizing miter bends	51
Bellows	51
Vacuum pumping section	24
Waveguide switches	30
Thermal expansion section	48
Gate valve	48
DC breaks	48
Dummy loads	27

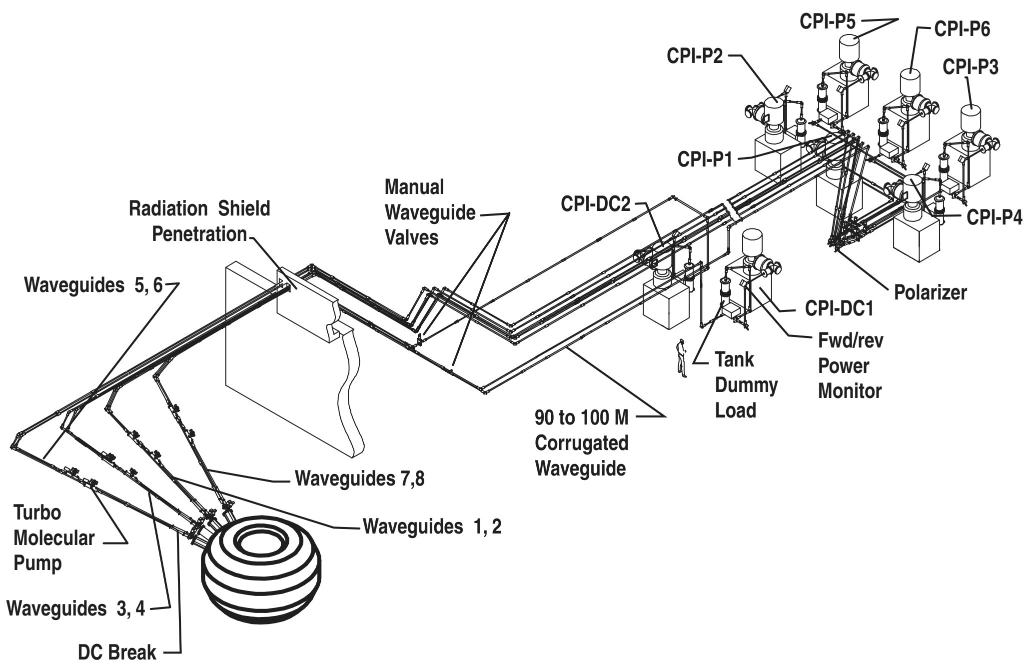

Fig. 2. Layout of the DIII-D EC System as envisioned for 2008.

Shown in Fig. 2 are both the six 1 MW class 110 GHz gyrotron systems which are either in operation or being installed in 2005, and the two depressed collector systems that are anticipated to be operational by 2008. The frequency of the second depressed collector gyrotron has been changed from 110 GHz to 120 GHz so that the DIII-D program can take advantage of the gyrotron development activity that the US gyrotron program is performing to supply the 120 GHz start-up gyrotrons for ITER. It is anticipated that these depressed collector gyrotrons will be more efficient, more reliable, and possibly have a higher power rating than the present 1 MW non-depressed collector gyrotrons. Since the new 120 GHz system will need everything from power supplies to launchers it is proposed that if all or most of the components were identical to those anticipated for ITER then it would require only a small investment to convert the DIII-D system into a test bed for the ITER EC system components.

3. ITER Test Stand

A test stand for ITER components can be configured within the DIII-D EC system if the rf conditioning unit and the transmission line components near the gyrotron conform to the 63.5 mm diameter chosen for ITER. The 120 GHz gyrotron that the US gyrotron development program is designing for ITER is anticipated to have an 88 mm output window aperture, which makes the coupling of the Gaussian output beam to the 63.5 mm diameter a simple task using a single focusing mirror. The transmission line between the gyrotron and the dummy load can be configured to include at least one of each of the components anticipated to be used on ITER [2]. If the dummy load includes a pre-attenuator, then power levels up to 1.5 MW cw can be supported. Because of thermal limits on the Transformer Rectifier (TR) presently installed at DIII-D, the maximum pulse length at full power will be limited to 400 s (the ITER nominal design) to support a longer pulse length the TR set would have to be upgraded. A concept of this configuration is shown in Fig. 3.

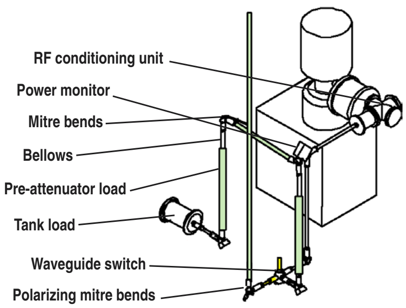

Fig. 3. Configuration of the DIII-D EC system as an ITER EC component test stand, with the major components to be tested identified. All components are 63.5 mm diameter, and evacuated.

4. Component Validation

It is a reasonable question to ask if testing of the ITER EC components at 120 GHz can validate for 170 GHz use. Since the primary issue for this validation effort is to demonstrate thermal management, then testing at 120 GHz puts the most stress on the components. Waveguide losses are generally proportional to the wavelength, so at 120 GHz the losses will be about 50% higher than at 170 GHz. Mode conversion losses scale as the wavelength to the 3/2 power, thus the losses at 120 GHz will be 69% higher than at 170 GHz. And if the 120 GHz gyrotrons can be operated at 1.5 MW then the waveguide components can be effectively validated for use at 170 GHz 2 MW.

5. Summary

Transmission line components suitable for ITER are basically the same as used on present fusion devices, but no transmission lines have been demonstrated at the 1 MW cw levels needed at 170 GHz or any other frequency. The next phase of EC System expansion at DIII-D can be configured to function as a test bed for ITER EC components. Testing to the nominal 400 s can be achieved, with longer pulses possible if the power supply system is upgraded. Testing at 120 GHz is more severe than at 170 GHz, and if the 120 GHz gyrotron can be operated at 1.5 MW, then the components should be able to be qualified for 2 MW at 170 GHz.

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