ECE system on ASDEX-Upgrade placed inline at the high power waveguide based transmission system

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Abstract—**It is proposed to provide the Electron Cyclotron Emission (ECE) feedback signal for MHD control experiments along the ECRH line-of sight. Experiments on TEXTOR have demonstrated a proof of principle [1], [2] and [3] motivate the further development and the implementation of such an ECCD aligned ECE system for NTM control in larger fusion machines. Implementation of such a system on ASDEX-Upgrade [4], based on waveguides equipped with a fast directional switch, is presented in this paper [6]. First results of open loop control of MHD modes in TEXTOR were presented in [2, 7].**

I. INTRODUCTION AND BACKGROUND

IN order to provide the feedback signal required to control the ECCD power deposition area with an accuracy of 1 to 2 cm. Existing schemes based on mode location, equilibrium reconstruction, and plasma profile measurements are limited in positional and temporal accuracy and moreover will become very complex when applied to ITER. To overcome these limitations, it is proposed to provide the feedback signal from electron cyclotron emission (ECE) measured in the reverse direction at the ECRH high power transmission line. Experiments on TEXTOR have demonstrated a proof of principle [2] and motivate the further development and the implementation of such an ECCD aligned ECE system for NTM control in larger fusion machines. Possible practical implementation of such a system on ASDEX-Upgrade, based on 87 mm corrugated waveguides equipped with separation system, is presented. The system proposed will complement the current ECE-ECCD feedback control system.

II. REQUIREMENTS

In order to set the requirements for an ECCD-aligned ECE diagnostic for NTM feedback purposes on AUG, the requirements for positional accuracy, resolution, and range of the magnetic islands to be diagnosed need to be translated into the ECE frequency domain. The minor radius of AUG is ~0.45 m; the major radius is 1.65 m. The maximum magnetic field strength is 3.1 T. For AUG experiments on NTM control, the 140-GHz ECCD resonance condition is typically met on the high field side at a normalized flux coordinate of ~0.7. The full-width ECCD power deposition profile is ~0.7 cm. This is very similar in size to the minimum island size that will have to be stabilized. The requirement on accuracy and resolution is therefore set to 0.7 cm, which corresponds to ~0.015 in normalized radial coordinate (or flux coordinate) A series of beam-tracing calculations for typical conditions of AUG show that the spatial requirement is met with an electron cyclotron frequency resolution of 1 GHz. To cover ~20 cm range in plasma minor radius, a frequency range of the order of 20 GHz should be adequate. Thus, the requirements on the ECCD-aligned ECE diagnostic includes a total of 20 data channels with 1-GHz separation centered around the ECCD frequency of 140 GHz.

Additional requirements, to be fulfilled, are that the separation system of the ECE from the high power transmission line has to accommodate possible frequency changes of the gyrotron (~300 MHz), while providing sufficient attenuation ~50 dB to prevent breakdown of the notch filter protecting the ECE detection system. (breakdown in the notch filter results in blocking of the ECE radiation and damage to the notch filter)

III. PROPOSED CONFIGURATION

Since a Fast Directional Switch (FADIS) [5] based on the quasi-optical interferometer principle will be installed at ASDEX for switching the power of a step tunable gyrotron between different launchers FADIS can be employed also as a frequency filter in a co-aligned ECE-ECCD setup serving the purpose of separating the low-power ECE signal [6]. Because the FADIS notch width is only a few MHz wide for at least 20 dB suppression, FADIS must be synchronously tuned to follow the center frequency of the gyrotron during the frequency droop of the gyrotron within the first 2 seconds of its pulse (~0.3 GHz) to measure ECE during this period. Nevertheless the non resonant output of FADIS can produce power levels in excess of ECE receiver loads even protected by an additional notch filter.

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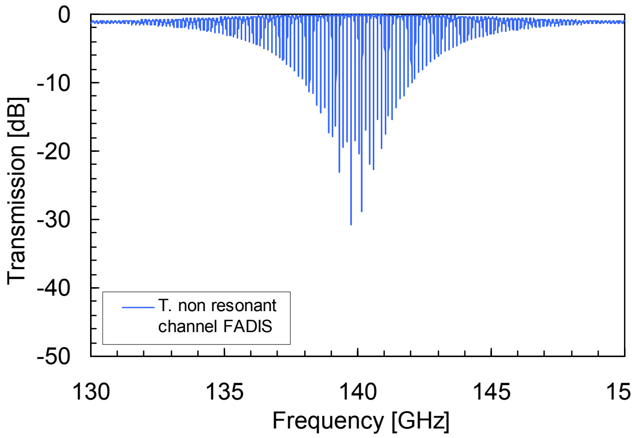

Figure 1 Transmission through the non-resonant channel of the FADIS: Maximum suppression of 30 dB is achieved.

This problem can be redressed by employing a second interference filter in tandem with the FADIS. However, in order to prevent interference and isolation decrease caused by back reflections of these filters, absorptive filters are the preferred solution. A good compact filter candidate can be a non resonant two-beam Mach-Zehnder-type interferometer [6] shown in Figure 2, coupled in series with FADIS, using the non-resonant output.

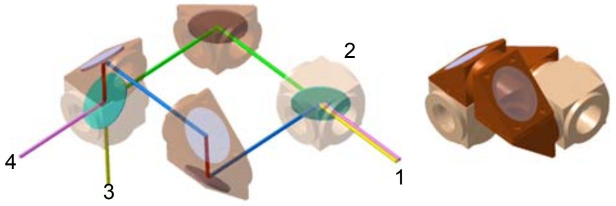

Figure 2 exploded (right) and composed (left) view of the design of a polarization insensitive 4-port Mach-Zehnder-type two-beam interferometer. It is used as a absorptive separation filter, for the ECE diagnostic signal (yellow, route port 1-3) from the stray gyrotron radiation signal (purple, route port 1-4), signal goes from right to left. The interferometer consists of 2 beam splitters in opposite beam planes and 4 mitre-bends. On this way a polarization insensitive configuration is made where the additional phase path (red) could be minimized to fit the required channel width of the ECE diagnostic. In this application port 2 and 4 should be terminated by loads

This system is very flexible in customizing frequency filter characteristics. In the regime of the gyrotron frequency the suppression notch width is only determined by the window thickness inside the beam splitters and independent from phase lag path. The reason for this is that at resonant frequencies they have maximum transmission and the phase lag path is switched off. Outside this frequency regime the beam splitters are operational and beating occurs between the frequency response of the interferometer and the window. The Mach-Zehnder design parameters are: two equal beam splitters with the parameters of the windows in the beamsplitters, n=1.951, tan d=2.9E4 and d=4.712 mm (Infrasil 301) and a phase lag length of 303 mm for Δf=989.38 MHz=7x141.34 MHz (141.34 MHz is periodicity of the FADIS). The result is presented in Figure 3. The route 1–3 (Figure 2) offers a minimum of 30-dB suppression of the gyrotron stray radiation, coming from the Tokamak, over a 0.3 GHz band.

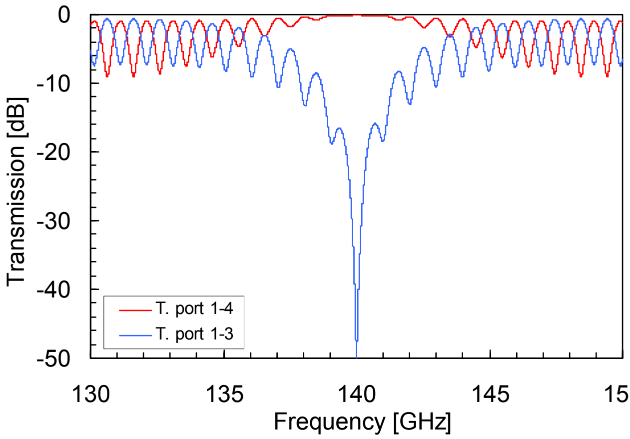

Figure 3 Result of a polarization independent Mach-Zehnder-type two-beam interferometer as shown in Figure 2 route 1–3 offers a minimum of 30-dB suppression of the gyrotron stray radiation over a 0.3 GHz band caused by start-up frequency droop of the gyrotron(< 2 s time). Combination with a synchronously tuned FADIS gives at least 50 dB suppression on 140 GHz.

In [8] a system is shown to measure scattered ECRH waves along the line-of sight which could be an option for a flexible ECE feedback system with tunable spatial resolution.

IV. CONCLUSIONS

Novel elements of an in-line ECCD feed-back control system are presented. A polarization independent two-beam interferometer absorptive filter will be placed in tandem with FADIS. A proof of principle was delivered at TEXTOR. Next step includes the demonstration on AUG and possible implementation at ITER.

V. ACKKNOWLEDGEMENTS

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