5. PARTICIPATION IN THE ITER PROJECT

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5.1. INTRODUCTION

This project included in 2005 activities in the following areas:

- Microwave reflectometry;
- Control and data acquisition;
- Non-inductive current drive;
- Information.

5.2. MICROWAVE REFLECTOMETRY

5.2.1. Main activities

The activities on microwave reflectometry have been related with the design analysis of the position reflectometer, development of an advanced FM-CW coherent reflectometer and experimental demonstration studies on ASDEX-Upgrade of plasma position/shape measurements in ITER relevant scenarios.

Concerning the design analysis of *the position reflectometer*, the Association EURATOM/IST has led a Physics Integration Task of the Fusion Technology Programme (TW3-TPDSUP) and is now in charge of a new Task (TW5-TPDS-DIARFA) entitled "Experimental assessment of ITER HFS waveguides".

Regarding the development of a prototype of *a coherent reflectometer*, the frequency synthesizer has been completed.

Concerning *plasma position/shape measurements,* a data base has been built to support a neural network approach towards real time density profile evaluation and first results were obtained.

5.2.2. Coherent reflectometer

The frequency synthesizer, the most complex and extensive part of the coherent reflectometer, was developed during 2005 (Figure 5.1). Both PLL and FPGA frequency control boards were tested and VHDL plus the microcontroller software was developed and fully tested. By the end of 2005 a fully operational hop/fast-hop/sweep synthesizer was fully tested and proven to work within the thigh timing requirements. Only minor software adjustments remain to be done to conclude this block. The remaining part of the coherent reflectometer system will be developed during 2006.

5.2.3 Plasma position reflectometer

5.2.3.1. In-vessel waveguide routing

The design of the in-vessel waveguide routings for gaps 3, 4, 5, and 6 modelled using CATIA was carried out. The routings for gaps 4, 5, and 6 are completed up to the port flange and await definition of the vacuum interface. The corresponding 3D CATIA models were sent to the ITER IT for validation and integration. As an example, the routing for gap 4 is shown in Figure 5.2.

Figure 5.1 – Prototype of the Frequency Synthesizer for Coherent Reflectometers

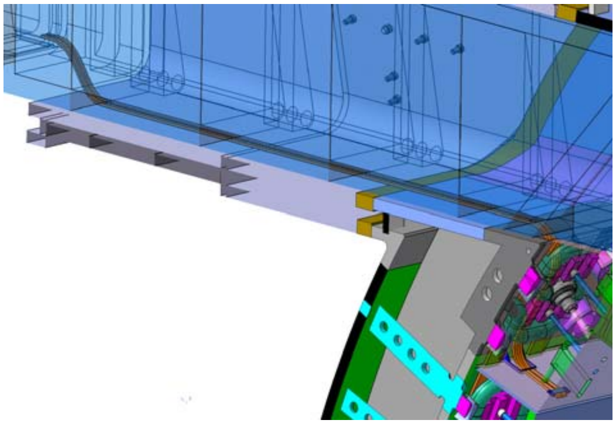

Figure 5.2 – Waveguide routing for gap 4, located between blanket modules 11 and 12. The waveguides are depicted in orange. The antenna and support structure can also be seen.

5.2.3.2. Waveguide electromagnetic performance[1]

In order to evaluate the electromagnetic performance of the waveguides, critical sections of the routing were simulated using the HFSS code. Both a straight section of waveguide and the most demanding bend were simulated. Because such complex waveguide chains will use joints/flanges, simulations contemplate also the assessment of the sensitivity to misalignments.

Numerical results indicate that straight sections of waveguide propagating the TE$_{01}$ mode are essentially loss free except for resistive wall losses.

Figure 5.3 shows that no mode conversions are observed in the frequency range 15 – 60 GHz.

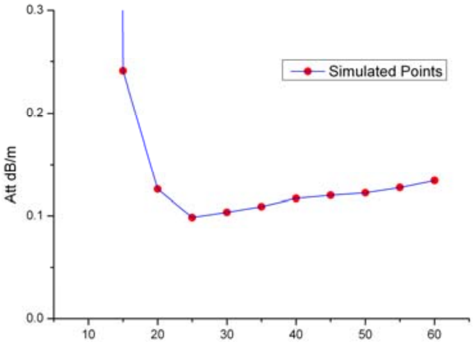

Figure 5.3 – Evolution of the transmission losses of a straight section of waveguide propagating the TE01 mode in the frequency range 15 – 60 GHz.

Curved sections of oversized waveguides may be more problematic as with mode conversion transmission losses increases which in the end may also modify the antenna pattern. Cross polarization can also occur as an effect of mode conversion.

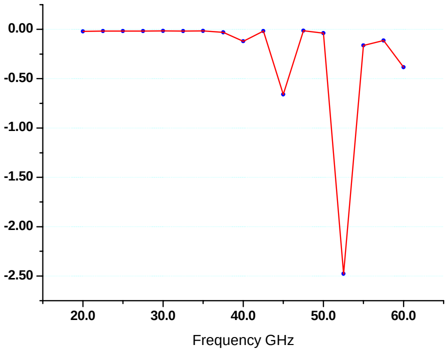

Figure 5.4 – Transmission losses for the most critical bend (gap 6). Simulation uncertainty is below ± 0.1 dB at 40 GHz and ± 0.5 dB at 60 GHz.

The above results show that transmission is essentially resonance free up to 40 GHz. Above this frequency the system performance can be reduced or even disable operation.

A straight section of waveguide was also used to investigate the sensitivity to misalignments in both E and H directions. As depicted in Figure 5.5, the waveguides are moderately sensitive to misalignments both in the E and H directions. However, the tolerance/precision requirements are within the maximum misalignment obtained with normal pin-aligned flanges.

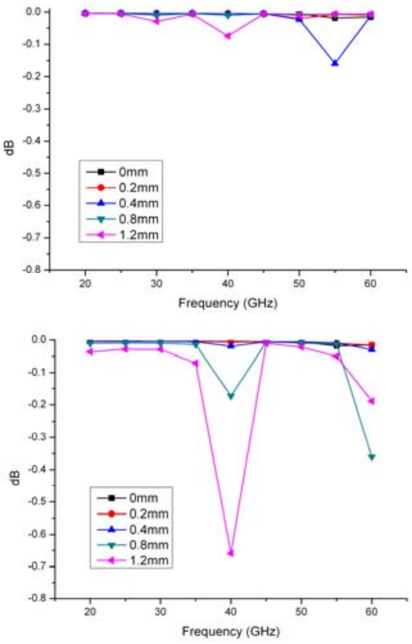

Figure 5.5 – Transmission losses due to misalignments along the E direction (upper) and H direction (lower) in comparison with a reference straight section.

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[1] With contributions from Dr. Dietmar Wagner (EURATOM/IPP Association – IPP, Germany) and Dr. Burkhard Plaum (IPF Stuttgart, Germany).

5.2.3.3. Thermal analysis

The antennas of the plasma-position reflectometer for ITER will be located between two blanket modules (for gaps 4, 5, and 6) and directly exposed to the plasma, thus being submitted to both nuclear heating and plasma radiation heating. Two major types of heat loads were considered in the simulations: plasma radiation and nuclear heating.

The results (Figures 5.6 and 5.7) show that the initial reference materials (copper and stainless steel) are not adequate to endure the predicted heat load.

The modified geometry made very clear the importance of adequate dimensioning and positioning of the support plates. With the introduction of another support and by using thicker plates the convergence temperature was strongly reduced, as more heat is conducted to the upper blanket, keeping the front section of the antenna at lower temperatures. Also, positioning the first support closer to the antenna front section (although exposing it to a higher nuclear load), prevents the accumulation of heat. Another important improvement is that the back support remains at a lower temperature. Although this setup allows the use of copper and stainless steel, a combination of a tungsten (or molybdenum) antenna and two thicker support plates, carefully positioned along the antenna body, would be a better solution.

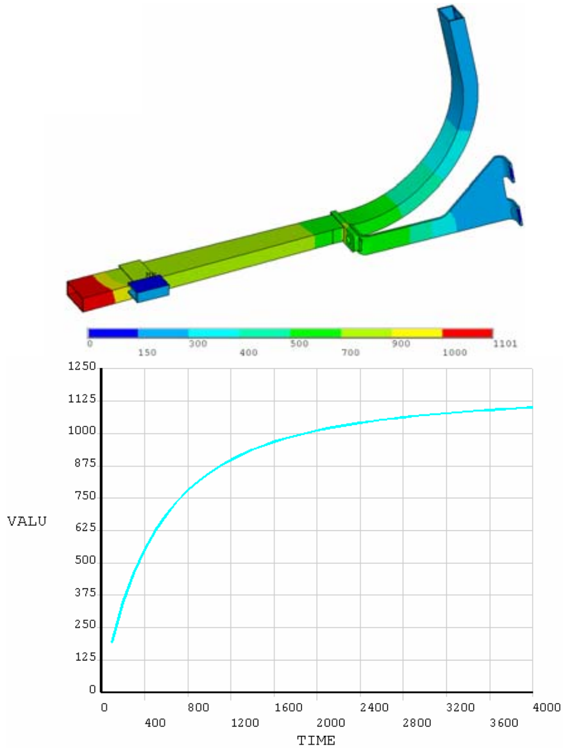

Figure 5.6 - Temperature distribution on the antenna plus waveguide structure after 4000 s.

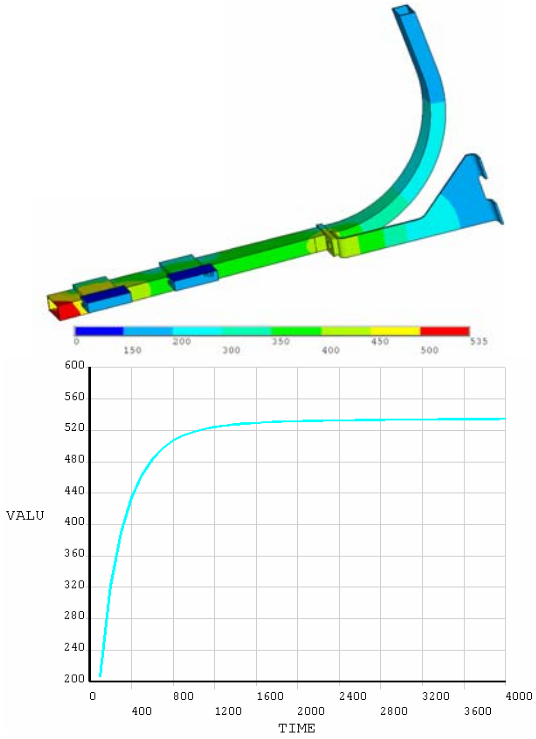

Figure 5.7 - Temperature distribution after 4000 s.

5.2.4. Plasma position/shape measurements in ITER relevant scenarios

To demonstrate real time profile evaluation a neural network based approach is being pursued; preliminary studies using experimental data from ASDEX Upgrade gave promising results[2].

An extensive density profile database for H-mode discharges was built, based on O-mode reflectometry data obtained in ASDEX Upgrade. This data base allows a statistical evaluation of the performance of the real-time profile inversion method. The application of the neural approach applied to those plasma scenarios proved to be quite robust to the effects that may decrease profile accuracy, namely plasma turbulence. It was also found that the method is not very sensitive to the lack of density profile data below $n_e=3.6\text{x}10^{18}$ m^{-3}, which cannot be obtained with O-mode probing. This is illustrated in Figure 5.8 where the performance of a trained neural network is compared with the results from the application of the traditional Abel inversion. In the case of the Abel inversion three different methods of initializing the density profile were used: (i) the initial assumed density profile; (ii) a curve obtained with a dynamic procedure and (iii) a linear extrapolation down to zero frequency.

The observed robustness is expected to provide a relief on the requirements and sophistication of the procedures

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[2] Details in chapter IV.

for group delay evaluation, allowing the use of more real-time friendly signal processing techniques.

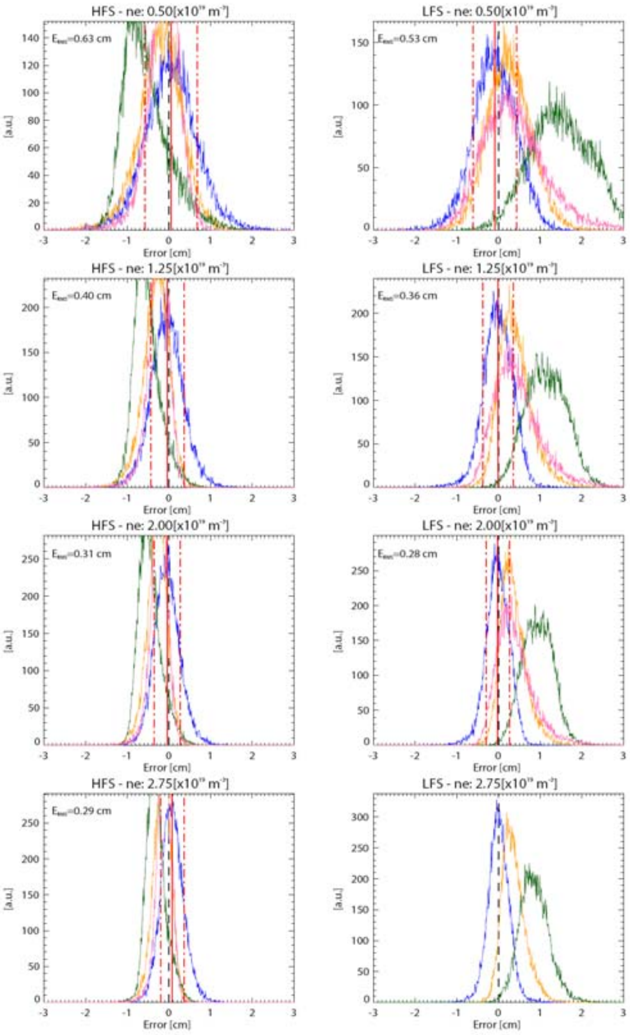

Figure 5.8 – Statistical distributions of position errors at four plasma density layers (ne=0.5, 1.25, 2.0 and 2.75x1019 m-3) corresponding to the inversion of a set of 17952 density profiles (affected by a density fluctuation level of 5% ne_sep). The output of the neural network is represented in blue. Shown also are: (i) the result of applying the standard Abel inversion to the probed group delay initialized with the assumed density profile (in orange); (ii) with a dynamical initialization (in magenta) and with a linear initialization (in green).

5.3. CONTROL AND DATA ACQUISITION

IST has started a formal collaboration with the ITER team on control and data acquisition. A senior researcher participated in Garching in a meeting for the definition of the working programme in this area.

5.4. NON-INDUCTIVE CURRENT DRIVE

5.4.1. Introduction

IST was envolved in 2005 in the design of ITER-like PAM lower hybrid current drive (LHCD) antennas[3]

5.4.2. ITER-like PAM LHCD antennas

5.4.2.1. Collaboration on the design of ITER-like PAM LHCD antennas

In response to a call from the EFDA Associate Leader for JET concerning the upgrade activities of its LHCD system, a project was set-up to design a new launcher based on the PAM (Passive Active Multijunction) principle, with CEA-Cadarache as the Leader Association. The first preliminary studies for this new LH launcher were carried out (in collaboration with CEA-Cadarache) mainly with regard to its coupling and directivity properties as a function of the electron density (above the cut off) — diverse studies being performed by the other intervening Associations — and were focused on the two most basic multi-junction shapes: the tri-junction and the bi-junction, together with the corresponding sets of internal phase shifters. The former was designed to launch a spectrum with the main peak located at $N_{//0}$=2.027

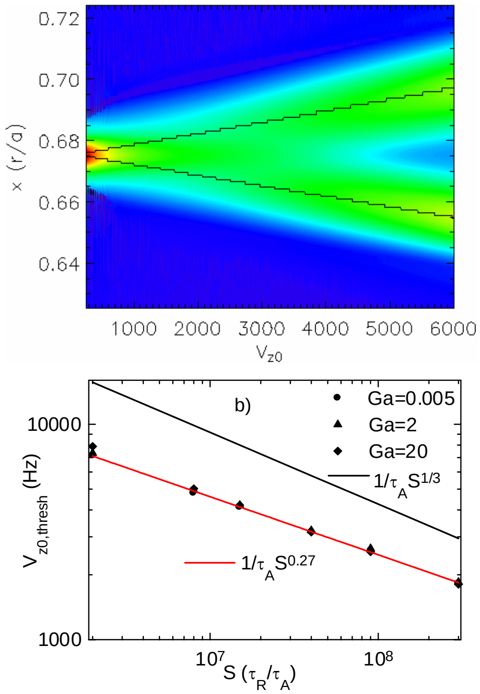

Figure 5.9 – Contour of the toroidal braking force exerted by static m=2,n=1 external magnetic fields on a rigid rotating plasma. Vertical axis indicates the radial direction and the plasma rotation lies on the x-axis (a). Rotation threshold for the transition between both regimes of reconnection (b).

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[3] Work carried out in collaboration with the Association Euratom/CEA. Contact Person: Alain Becoulet.

whereas for the latter $N_{//0}=1.9$ was chosen instead. Passive waveguides with various depths (λ/8, λ/4, 3λ/8 and λ/2), including most of their combinations, were investigated for both designs and for every situation various feeding phases were tested as well. With the adoption of the bi-junction based antenna, an important study was carried out to allow for the largest injected power compatible with other constrains. This led to a launcher design having 20 mm wide active waveguides and with the passive ones reduced to an 8mm width, as the one being proposed for implementation, due to its coupling endowments as well as to the potential to reach an injected power somewhat in excess of 5 MW (at a 25 MW/m^2 power density). These studies were included in the final report of the entire project.

This year saw also the start of a thorough study (also in collaboration with CEA-Cadarache) of the coupling features of Tore Supra's LH antenna known as C3, for which the properties of the full launcher (in what its coupling to the plasma is concerned) will be modelled and the ensuing theoretical results compared to the corresponding experimental measurements. It is the first time that a study of this magnitude, i.e. including the full waveguide array of the entire launcher, is undertaken for the C3 (with its 288 waveguides divided in 16 modules). The ultimate goal, though, is to characterise the behaviour of LH launchers in general when they face the plasma and, in particular, that of the new PAM (Passive Active Multijunction) antenna under construction for Tore Supra, thus creating important tools for the analysis of experiments.

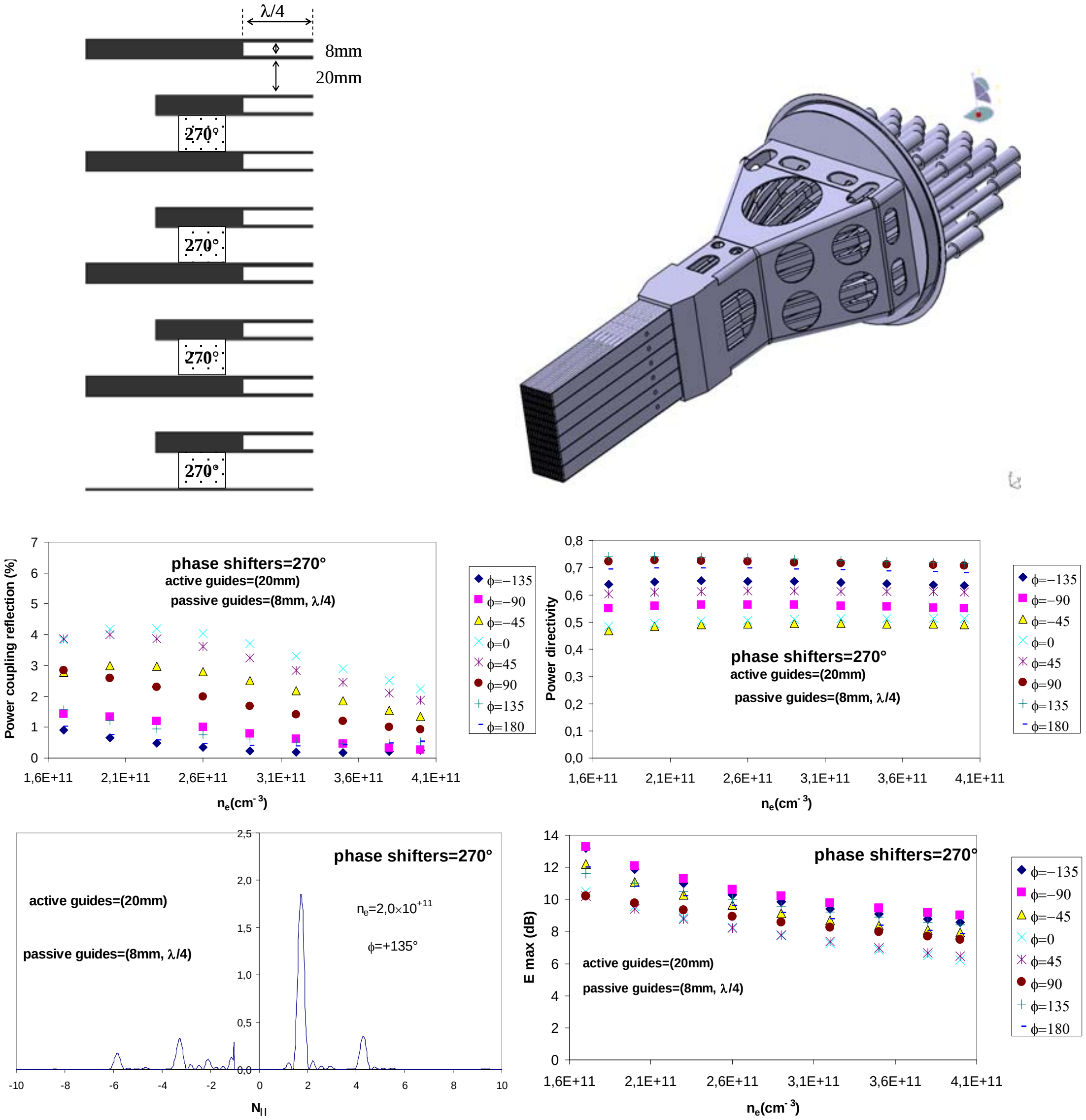

Figure 5.10 – View of the PAM LHCD launcher designed for JET, and analysis of its coupling capabilities.

5.5. INFORMATION

IST has proceeded with the divulgation of the ITER project to the general public, industry and research units. The following actions were performed in 2005:

- Participation in the Fusion-Industry Workshop, held in Madrid, in 1 and 2 June. Prof. Carlos Varandas was the Co-chair of the working group on Industrial Policy Issues;
- Publication of articles in the main Portuguese newspapers and participation in television programmes about ITER;
- Organization of a Workshop in 24 November, at IST, for the divulgation of the ITER project to the Portuguese Industry and Research Units. This Workshop had about 114 participants;
- Participation in the workshop “ITER: Opportunities for European Industry”, held in 13-14 December, in Barcelona, with a stand and 500 participants.