8. PARTICIPATION IN THE ITER PROJECT

C.A.F. Varandas and M.E. Manso (Heads), A. Malaquias, J. Santos

8.1. INTRODUCTION

The Portuguese participation in the ITER Project has included activities in the following areas:

- Diagnostics design and integration;
- Microwave reflectometry;
- ITER Negotiations.

8.2. DIAGNOSTICS DESIGN AND INTEGRATION

8.2.1. Introduction

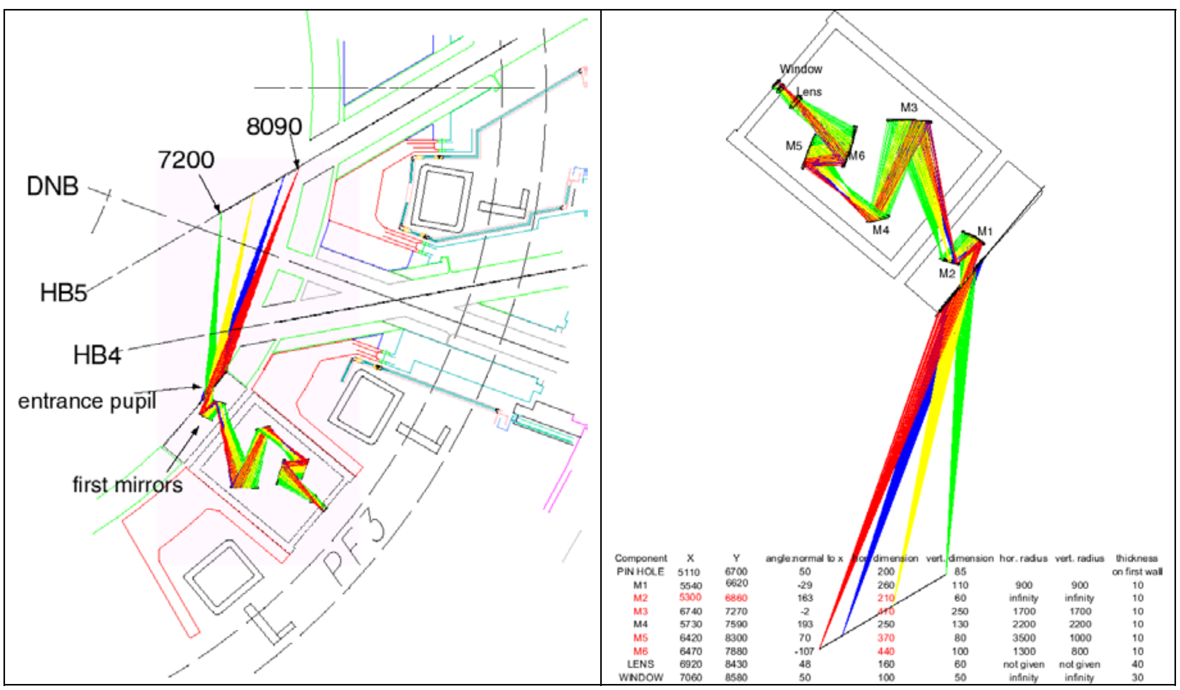
Prof. Artur Malaquias belonged during 2002 to the ITER International Team, working at Garching in the design and integration activities related with:

- Motional Stark Effect Diagnostic;
- Charge Exchange Recombination Spectroscopy;
- X-ray System.

8.2.2. Motional Stark Effect Diagnostic

The following main activities were performed in 2002:

- Coordination of the physics studies to evaluate whether the Motion Stark Effect is still linear or, due to the high ITER Stark field, will become quadratic in the B-field[1];
- Integration of a preliminary 4 mirror system in the equatorial port number 9 (eport9)[2];
- Coordination of the studies of spatial resolution and Doppler shift for viewings from different equatorial ports looking to the heating beams(HBs)[2];
- Relocation of the diagnostic optical system to eport[3] according to results of former studies (Figure 8.1);
- Development of a model to determine the effect of mirror coating by Be on the polarization state of light emitted by the HBs.



Component	X	Y	angle normal to x	hor. dimension	vert. dimension	hor. radius	vert. radius	thickness on first wall
PIN HOLE	5110	6700	50	200	85			
M1	5540	6620	-29	260	110	900	900	10
M2	5300	6860	163	210	60	infinity	infinity	10
M3	6740	7270	-2	410	250	1700	1700	10
M4	5730	7590	193	250	130	2200	2200	10
M5	6420	8300	70	370	80	3500	1000	10
M6	6470	7880	-107	440	100	1300	800	10
LENS	6920	8430	48	160	60	not given	not given	40
WINDOW	7060	8580	50	100	50	infinity	infinity	30

Figure 8.1 – MSE at eport3 looking at HB5

---

[1] Work carried out by the European Union Home Team (EUHT).
[2] Work in collaboration with the Padova Laboratory of the Association EURATOM/ENEA.

A numerical code was developed to take into account polarization effects by mirrors. A formulation was also developed to consider light polarization state behavior due to Be coating on first mirrors. This work allows to determine best mirror material to account for these effects (Figure 8.2);

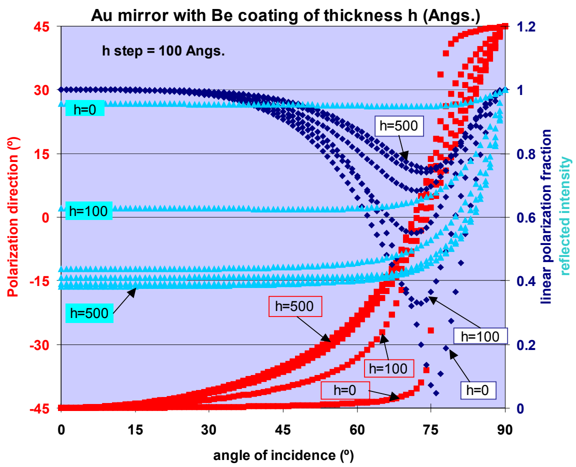


Figure 8.2 – The graph shows how Be coating (h) affects the polarization state of light (linear polarization fraction), direction and total reflected intensity.

- Design of an optical viewing system (edge to middle radius coverage) to be integrated in eport3 following the guide lines from the previous study;
- Study of the cumulative effect on the polarization state of light due to the multiple mirror arrangement for MSE periscope;
- Study to evaluate the possible utilization of upper ports to perform MSE measurements at plasma core with the required resolution.

Previous studies have shown that the only equatorial locations for MSE to perform according to requirements was eport1 or eport[2] (depending in which HB to be used) both allocated for the test blanket module.

MSE cannot achieve the required spatial resolution from available equatorial ports. A study was developed to evaluate the spatial resolution, Doppler shift and intensity levels by using upper ports to perform the measurements. Also a port reallocation is under study to shuffle a diagnostic port with eport[2] from where MSE can perform according to requirements (Figure 8.3). Results have shown that either there is not good enough spatial resolution or the normalized collected intensity is too small. Full clarification of the last point is depending on beam emission simulations.

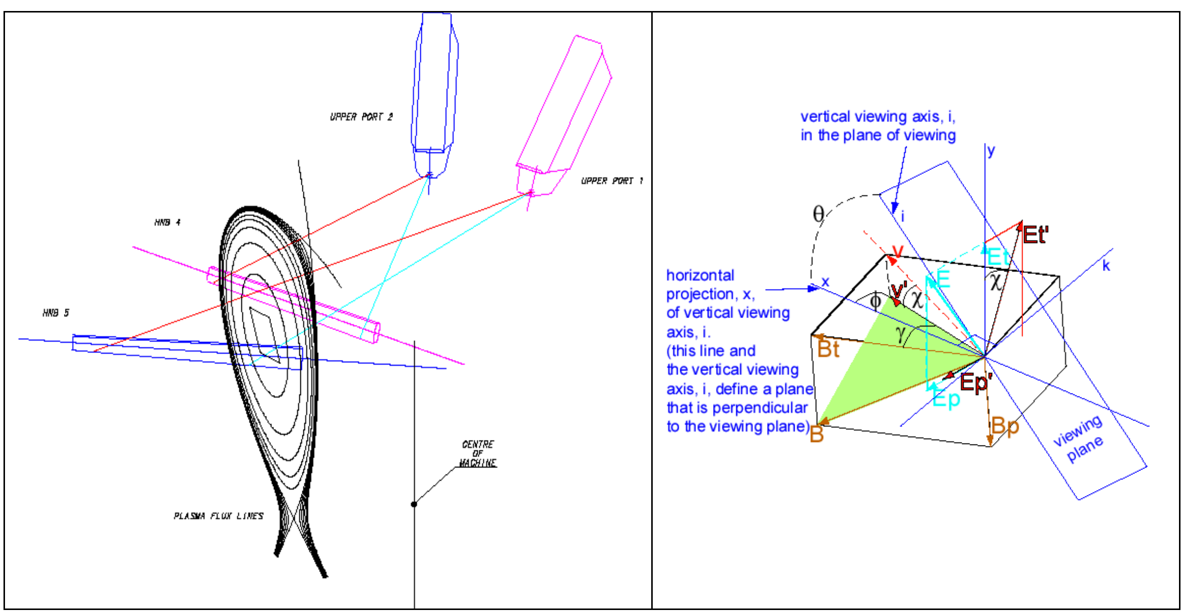


Figure 8.3 – Geometric setup for MSE from uport1 and uport2

8.2.3. Charge Exchange Recombination Spectroscopy

The following main activities were carried out in 2002:

- Proposal and coordination of careful comparison of feasibility studies performed by EUHT and RFHT[3];
- Draft of the possible optical system arrangements[4];
- Preliminar diagnostic periscopes implementation (uport4 core and edge plus a core system in uport3)[5];
- Design of the optical systems for uport4 (core and edge);

A ray tracing program was used to perform the first designs of the CXRS diagnostic optical systems located on uport4, above the DNB. Integration of the edge system was initiated (Figures 8.4 and 8.5);

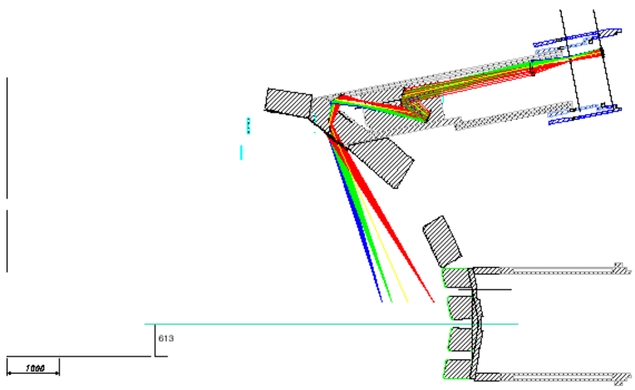


Figure 8.4 Edge CXRS optical system

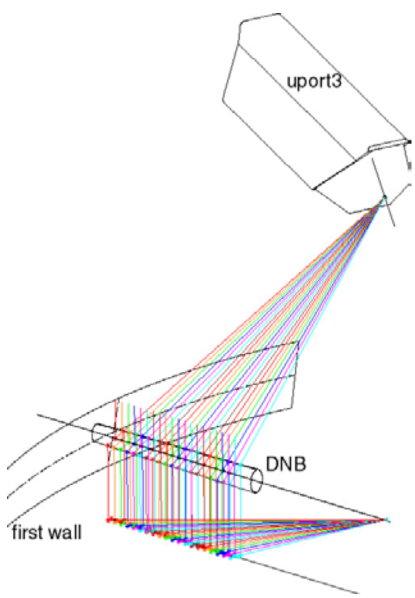


Figure 8.5 – Core CXRS viewing lines arrangement

- Development of a feasibility study to perform Beam Emission Spectroscopy measurements on the DNB;
- Re-design of the overall viewing systems and their re-allocation in order to allow high spatial resolution measurements of CXRS, BES and MSE combined version.

Due to the difficulties faced by MSE system to diagnose the plasma core using the heating beams it was decided to use the CXRS optical systems to make MSE measurements on the DNB by the intensity ratio method. An optimized arrangement for CXRS/MSE was proposed and is under design (Figure 8.6).

- Development of spatial resolution and Doppler shift studies for the new arrangement;
- Beginning of the integration of periscopes in different ports[5].

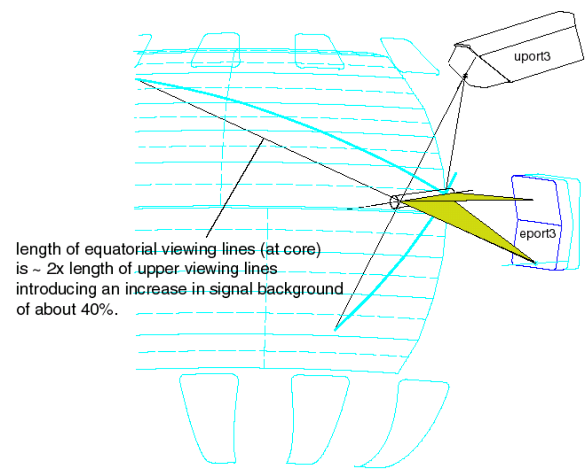


Figure 8.6 – Edge system at uport4 is replaced by pure toroidal edge system at eport3 (upper system). An edge to core system is introduced at eport3 (lower system) allowing the retrieval of edge poloidal velocity. The eport3 systems will enable MSE measurements of very high spatial resolution with retrieval of magnetic field pitch angle and Er.

8.2.4. X-ray system

The following main activities were performed:

- Coordination of the estimation studies of the diagnostic performance[5];
- Coordination of the draft design of a new arrangement for the XRCS1 (Figure 8.7);
- Use of previous diagnostic spectrometer setup in order to implement a multiple chord direct view system in eport9 (16 lines) and uport9 (5 lines);
- Coordination of the tomographic analysis of the new system[5];

[3] RFHT means Russian Federation Home Team.
[4] Work in collaboration with the Russian Federation Home Team (RFHT).

[5] Work carried out by the EUHT.

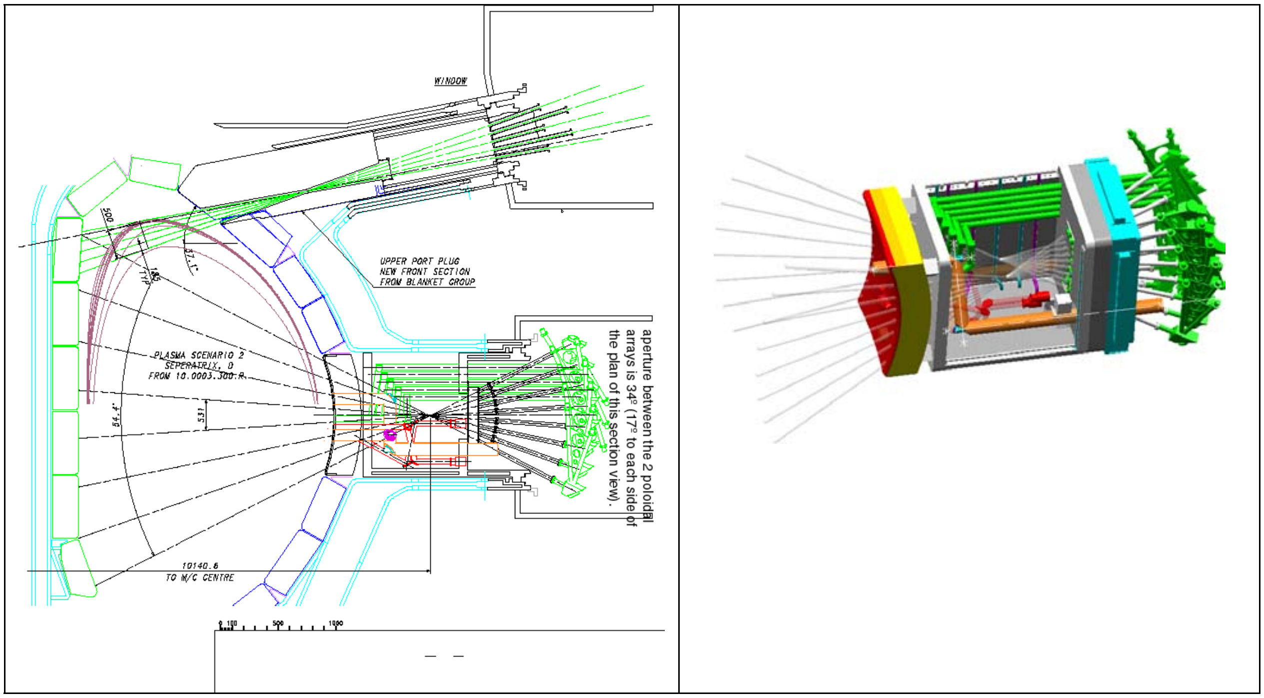


Figure 8.7 – New arrangement for multichannel X-ray

- Coordination of the redesign of the XRCS system at uport9 in order to have an imaging system instead of a multiple chord system6 (Figure 8.8);
- Coordination of studies to evaluate the consequences of converting the equatorial direct viewing system to an imaging one (going on activity)[5].

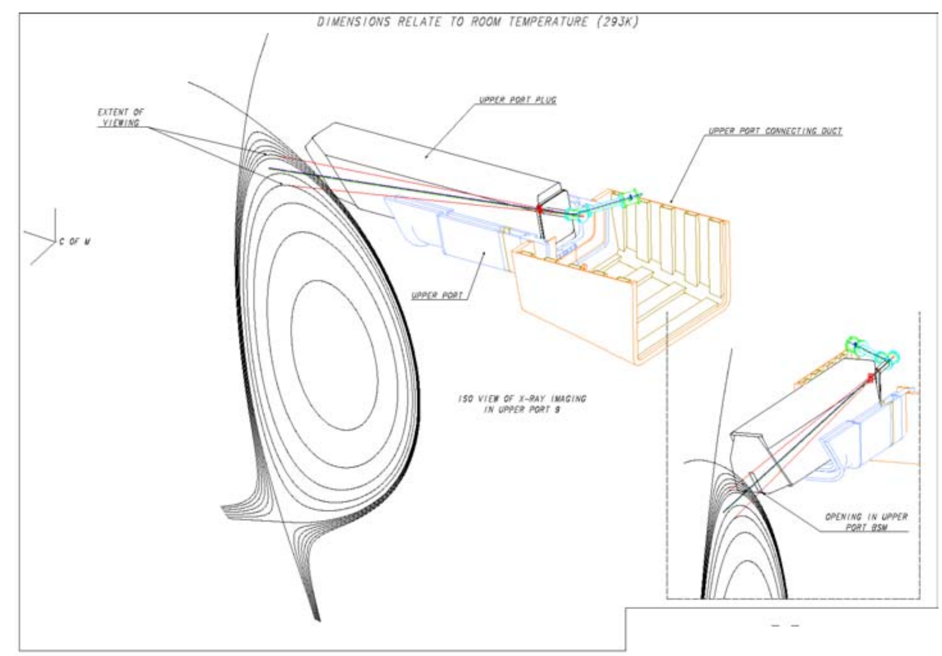


Figure 8.8 - Imaging X-ray system for uport9

8.2.5. Interfaces between diagnostic systems and machine systems

Changes on the confinement rules of ITER have driven specific studies and discussions to adapt the diagnostic vacuum boundaries interfaces (implementation of new arrangements on uport10, eport9 and eport11). Second vacuum enclosures were replaced by local strong primary vacuum boundaries and solutions have to be found in a case by case assessment. Interface areas like windows, wave guides and direct coupled systems are being design in order to match the new requirements. An example at eport11 (work on progress) is given in Figures. 8.9 and 8.10.

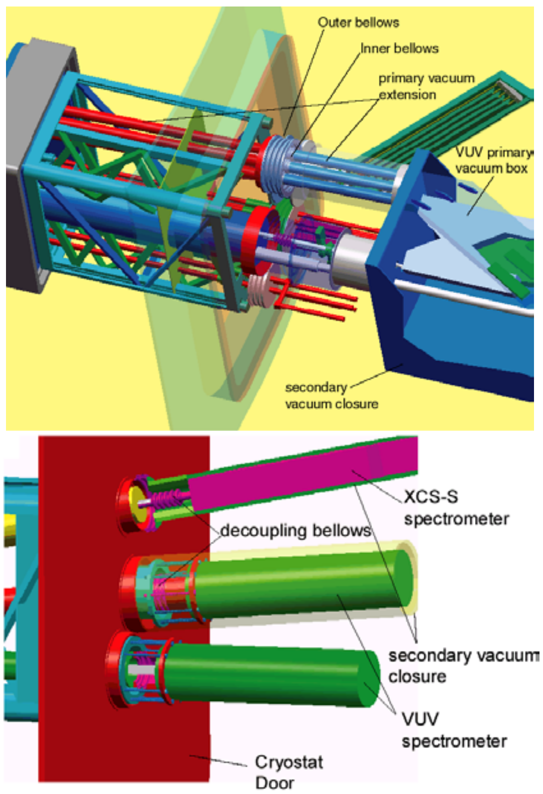


Figure 8.9 – Old arrangement at a) eport11 and b) uport10. Secondary enclosures connected to cryostat door are to be removed and its function implemented in a 'localized per diagnostic' way implying rearrangement of diagnostic distribution.

A new concept for port plug water feeding was developed in order to eliminate the existing piping system due to possible interference with diagnostic layout arrangement (Figures 8.11 and 8.12).

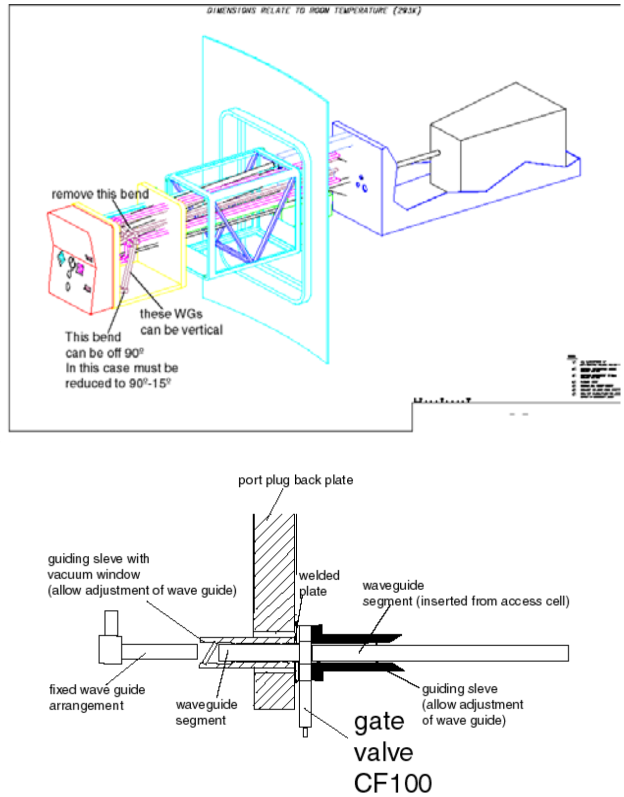


Figure 8.10 – a) Rearrangement of diagnostics in the port plug and b) example of introduction of local safety and confinement rules for wave guides compatible with automatic coupling (work in progress).

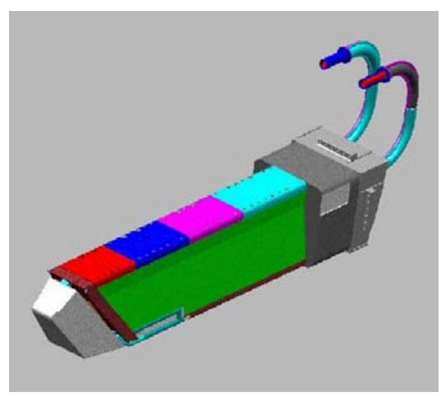


Figure 8.11 - Actual water feeding pipes can have an interference with diagnostic components.

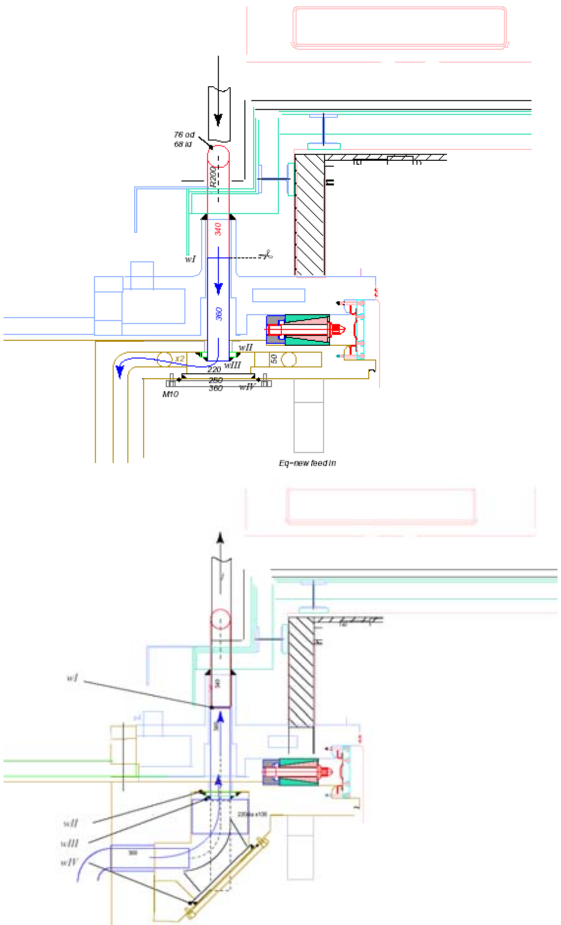


Figure 8.12 – Two equivalent proposed arrangements for port plug water feeding where the connection is made through the port extention avoiding pipes to be in front of diagnostic lines.

8.3. MICROWAVE REFLECTOMETRY

8.3.1. Introduction

Microwave reflectometry has been proposed to complement the magnetic diagnostics for position and shape control in ITER long pulse discharges. Presently, this approach is being experimentaly tested on ASDEX Upgrade (AUG) by investigating further capabilities of the diagnostic in order to demonstrate if new measurements that are required for ITER are possible, such as those of the magnetic field configuration as well as plasma position and shape. The work involved has been:

- Development of a software tool to simulate O/X mode reflectometry experiments aiming at demonstrating the possibility of measuring Bt (r) with combined O and X mode probing. First dedicated O/X mode measurements have been performed at the LFS;
- Assessment of the reliability and accuracy of plasma position measurements from reflectometry.

8.3.2. Position control

Position control requires the monitoring of the plasma edge gaps (vital for machine protection) with a set of on-line measurements of the scrape-off-layer (SOL) density, at various poloidal positions. FM-CW reflectometry in AU showed that radial variations of the plasma column occurring during pre-programmed horizontal as well as vertical plasma displacements can be followed with sufficient accuracy (~1 cm) in discharge phases with roughly constant average density.

Shape control requires measurements of the location of a density layer at or immediately inside the separatrix. If transport along field lines is fast enough to guarantee constant plasma parameters on flux surfaces, density is expected to be constant within magnetic flux surfaces. This is usually the case of closed flux surfaces inside the separatrix (and to some extent even in the hot main chamber scrape-off layer far enough from the divertor throat and in the absence of Marfes etc.). Assuming that the density is constant on the flux surfaces, an absolute relation between density near the separatrix and poloidal flux is needed.

Using a scaling relation between the average linear density and the density at the separatrix, the evolution of the separatrix position along the discharge is estimated, simultaneously in the inner and outer midplane, of ohmic L-mode density limit and ELMy H-mode discharges in AUG, both exhibiting large density variations.

Figure 8.13 shows the positions of layers with absolute (constant) density obtained by reflectometry at both sides in a standard density limit shot (#15555). From the plots the profile changes at the edge can be tracked, namely those occurring for t~1.1 s and the increase of the edge density in the density ramp-up phase. During the time window where the average density does not change significantly, including a radial position sweep (at t~1.5 s) for diagnostic purposes, the results from reflectometry are in good agreement with magnetic data since the density at the separatrix should also be constant. Obviously, during the density ramp-up phase, layers are tracking which are continuously shifting across the separatrix, i.e. the assumption of a constant separatrix density is no longer valid.

In fact, careful examination of the intersection between these curves and the separatrix position (Rin and Rout) reveals an increase of the separatrix density that scales well with the increase of the line average density. In many plasma machines such a scaling law (that provides an estimation for the density at the separatrix) has been found. Different fractions of the line averaged density (Figure 8.14) were used to find the scaling factor that leads to a better agreement between the estimation of the separatrix position using reflectometry and the magnetic data. The best match found occurs around 38% where the total verified RMS deviation was ~ 0.6 cm.

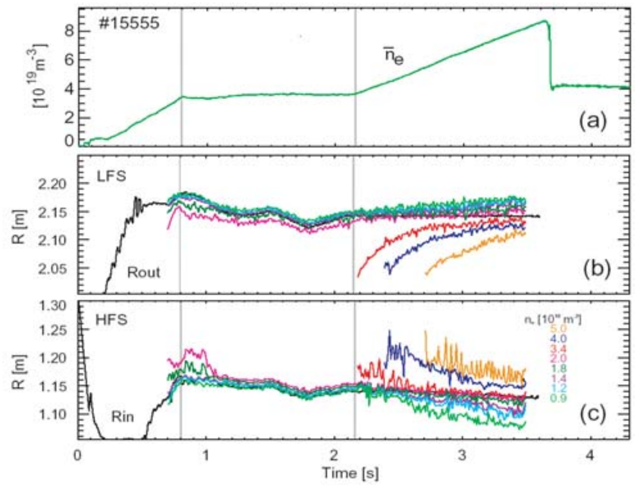


Figure 8.13 - Temporal evolution of: (a) line average density from interferometry; (b) position of the magnetic separatrix at the low field side (Rout) inferred from the magnetic diagnostics and position of layers with constant density from reflectometry; (c) position of the magnetic separatrix at the high field side (Rin) and position of layers with constant density from reflectometry.

Good results were also obtained for standard H-Mode shots, with type I ELMs, e.g. shot #14829. In this case the scaling factor that leads to the best agreement with the position of the magnetic separatrix at low field (Rout) and high field (Rin) sides, inferred from the magnetic diagnostics, is 42% with a total RMS deviation 0.85 cm.

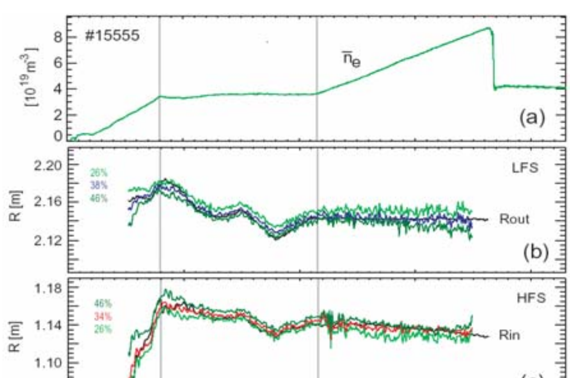


Figure 8.14 - Plasma position from reflectometry tracking density layers related to the line average density by different percentages. The best match between the data from reflectometry and from the magnetics is obtained for a 38% scaling on the LFS (blue curve) and for 34% on the HFS (red curve).

8.3.3. Development of new generation broadband reflectometer

Results in present reflectometry experiments reveal difficulties to probe the plasma core due to the low input power at high frequencies (> 75 GHz), long propagating distances and strong refractive effects. New generation reflectometers that can resolve those problems are crucial for ITER due to the longer transmission lines and greater propagating distances in the plasma that will increase the difficulties.

IST/CFN has begun the study of a coherent reflectometry system for broadband operation and fast sweep using coherent generation of both the probing signal and local oscillator signal for the receiver. It will incorporate heterodyne receiving techniques with both phase and quadrature detection.

The coherent signal generation technique allows the two main signals, the transmited signal and the local oscillator for reception, to be generated from a single variable source by appropriate frequency conversions.

In this new concept the frequency sweeping rate is not limited by the phase locked loop time response, which is a significant advantage in view of the necessity to use ultra fast sweeping to diminish the destructive effects of plasma turbulence.

This development will require the use of state of art microwave electronics to ensure signal purity at the various stages of frequency conversion along with precise filtering and frequency planning. Actually the microwave and millimeter wave electronics components include various types of GaAs MMICs. The amplifiers can provide power levels of several hundreds of milliwats at the millimeter wave range (3 –110 GHz). The integration of these components in the development/construction of new reflectometer diagnostics will result in an increase of several milliwats of power launched into the plasma.

The proposed development will enable the possibility of sweep times faster than the present 20 μs (state of art in 2003), while enhancing significantly the signal detection techniques.

8.3.4. Divertor Reflectometry on ITER

8.3.4.1. Introduction

IST/CFN has begun the study of the implementation of Reflectometry (Microwave/mm/sub-mm Wave) on the ITER divertor corresponding to the adaptation of solutions proposed in Varenna 1997 to the smaller ITER scaling. This work includes several issues such as transmission line and antenna performance, cross talking, spurious reflections, etc. It is crucial to test all the proposals, namely by constructing a mock-up system of the cassette insert, transmission line including bends and gaps, vacuum windows, conversion box, in parallel with simulation studies.

8.3.4.2. Waveguides

(a) *circular:* the corrugated circular waveguides can only be used for f ≤ 300 GHz.

(b) *rectangular and square waveguides*: The radiation pattern of rectangular and square waveguides should be

studied and the effects of the propagation inside the space (80 mm) between the antenna and the divertor plasma facing components.
The possibility of cross-talking between different channels should also be considered.

8.3.4.3. Frequency ranges:
Low frequencies (9 - 18 GHz): (i) for the proposed waveguides it is expected that attenuation and dispersive effects is significant; (ii) in the plasma it should be analysed if the WKB approximation is still valid; The width of the reflecting layer and the spatial resolution should also be determined.
High frequencies 110 - 300 GHz : there is no experience in broadband techniques in this frequency range

8.3.4.4. Technology for millimeter and submillimeter wave reflectometry, ECE and ECA diagnostics
The availability of microwave sources for reflectometry ECE and ECA diagnostics, to probe the extremely high densities expected on ITER, was studied. In the range of 30-600 GHz solid state tunable oscillators such as VTOs and HTOs followed by broadband active and passive multipliers offer the best choice for fast swept sources able to operate in large bandwidths. Fundamental mode oscillators for the lower frequencies are available although as the frequency becomes higher the tuning span gets narrower (approximately 2 GHz range at 110 GHz, while 4 GHz range at 40 GHz). The most probable scenario for the higher frequencies will be that multipliers would still be required for broadband operation. In addition, the use of heterodyne detection techniques in swept operation also requires the master oscillator (before multiplication) to operate at frequencies where PLLs or frequency synthesizers can be used, that is up to 26 GHz (eventually up to 40GHz).

Table 8.1. shows the state of the art of source performance considering broad band active multipliers up to 110 GHz (or multipliers followed by amplification) in full waveguidebandwidths and up to 140 GHz in moderate bandwidths. This can be followed by high efficiency diode multipliers for the ranges above. The near future prediction is based on active multipliers/amplifiers up to 110 GHz and passive ones above that. (Most of these products are already available while some are only for restricted/classified use, however expectedly commercially available within 10 years).

Another problem is related to the sensitivity of the receivers, which is limited not only by the plasma noise (whenever detectable) but essentially by the IF bandwidths. These parameters must be larger than the coherence bandwidth of the plasma and local oscillator signals. This fact suggests again that rather than using fundamental gunn oscillators it might be advantageous to use cleaner sources at low frequency followed by multipliers which might give the same power output with a much better phase noise performance. These sources with low phase noise could be phase locked gunn or inpatt oscillators or better lower frequency multiplied sources.

Freq. range Band GHz	State of art Power dBm	In 10 Year Power dBm	Receiver NF Harm. mixer	Receiver NF Fund. mixer
Ka 26.5 - 40	27	30	-	7
Q 33 – 50	23	27	-	8
U 40 – 60	20	23	-	8
V 50 – 75	17	20	13	8
E 60 – 90	14	17	16	9
W 75 - 110	10	13	22	9
F 90 – 140	6	10	24	9
D 110 – 170	3	7	30	10
G 140 – 220	0	3	34	12
220 - 350	-4	3	>35	14
350 - 600	-6	0	>40	15

Table 8.1 - Performance of signal generators for the range 30-600 GHz as in 2003 and expected evolution in the next 10 years.

Optical sources down converted to the sub-millimeter region would be a solution for large to extremely large bandwidth sources, but the phase noise of the resulting signal would be extremely strong for broadband swept operation. Therefore, the bandwidth of the receiver must be extremely large and the noise from the plasma (or just thermal noise) would then represent the main limitation. Although some recent developments in tuned laser seem promising we are still a little far (2003) from the desirable figures for a good sub-millimeter swept heterodyne receiver.

On the sub-millimeter bands it is possible to predict the availability of series of moderate bandwidth tunable oscillators multiplied by diodes in corner cube or other quasi optical structures. Also there is still the possibility of using BWO tubes extending above 2000 GHz, however the possible low phase noise obtainable with todays technology supplants the power advantage of the electron devices at the sub millimeter wave bands.

8.4. ITER NEGOTIATIONS

Prof. Carlos Varandas is a member of the delegation of the European Union to the ITER Negotiations, in his function as Chairman of the Steering Committee of the European Fusion Development Agreement.

In 2002 Prof. Varandas has attended five meetings and he has also chaired the 6th meeting of the "Negotiator's Standing Sub-Group" held in Vandellós (Spain).