8. PARTICIPATION IN THE ITER PROJECT

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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 2003 to the ITER International Team, working at Garching in the frame of the contract FU05-CT2003-00025. He has been involved in:

- Diagnostic systems design and co-ordination of design effort;
- Integration and distribution of diagnostic systems;
- Participation on and co-organization of scientific meetings

The diagnostics systems addressed on these activities were:

- *Vacuum coupled diagnostics* - Neutral Particle Analyser (NPA), divertor Vacuum Ultraviolet (VUV-D), X-ray Crystal Spectrometer Survey (XRS-S), Vacuum Ultraviolet Survey (VUV-S);
- *Active spectroscopy diagnostics on neutral beams* - Motional Stark Effect (MSE) and Charge Exchange Recombination Spectroscopy (CXRS);
- *Non-coupled passive spectroscopy diagnostics* - X-ray Crystal Spectroscopy Array/Imaging (XCS-A/I), Reflectometry Micro Wave systems in the Low Field Side (R-LFS) for main plasma, Time of Flight Refractometer (R-TOF) and Doppler Shift Radar Reflectometer (R-RDS)

8.2.2. Main activities

The following main activities were made in 2003:

- Relocation of some systems to more suitable ports;
- Upgrade of the microwave diagnostics implemented in eport#11 to include the Doppler reflectometry system and the integration of individual motion decoupling devices for the wave-guides (Figure 8.1);
- Elimination of the graphite reflectors X-ray array and its replacement by a new system at eport#9;
- Redesign in eport#9 of the X-ray survey and the VUV survey in respect to their function covering now the spectral range by means of 6 sub-bands and to their vacuum chambers and refurbishment procedures;
- Development of a new arrangement for the port plug shielding blocks and inter-space shielding;
- Replacement of the previous X-ray system by a completely new design based on imaging crystals and relocated to eport#9;
- Definition of a new positioning of the ECE system in order to optimise the plasma coverage;
- Integration at the upper port level of two newly designed diagnostics: the VUV-imaging (Figure 8.3) and the upper imaging X-ray (Figure 8.4).

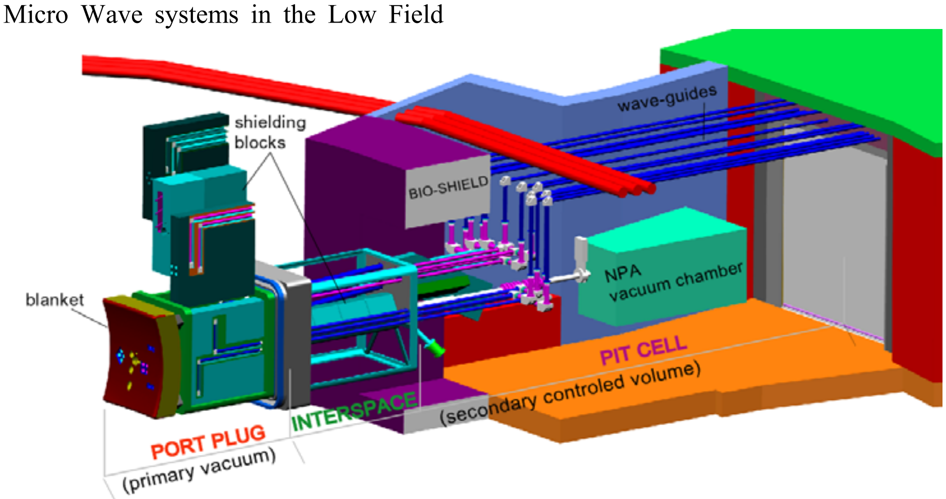


Figure 8.1 – Overall layout of eport11 with new arrangement of wave-guides containing the motion decouplers.

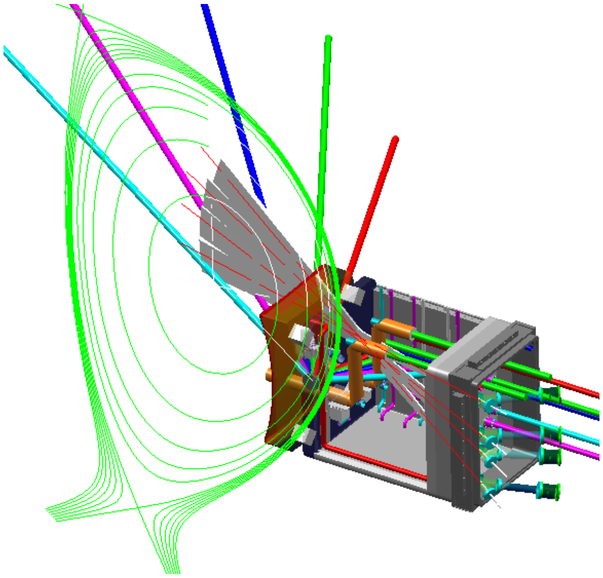


Figure 8. 2 – New eport#9 arrangement including the 4 imaging x-ray sub-sets and the repositioning of ECE (orange system) and of the toroidal polarimeter/interferometer beam lines (colored lines)

- Design of the optical periscopes for the CXRS and MSE diagnostics. This activity of high importance for the project has implied the relocation of the ITER ports in order to allow the complete plasma coverage by the MSE periscopes. Diagnostic eport #16 has been swap with test blanket module eport#2. Another consequence of the implied study in the periscopes design was the repositioning of the Diagnostic Neutral Beam (which shares epor#4 with the HB) to point to plasma centre. The optical design of the periscopes has been made using geometric ray tracing (Figure 8.5) and optimised in Zemax (Figure 8.6)

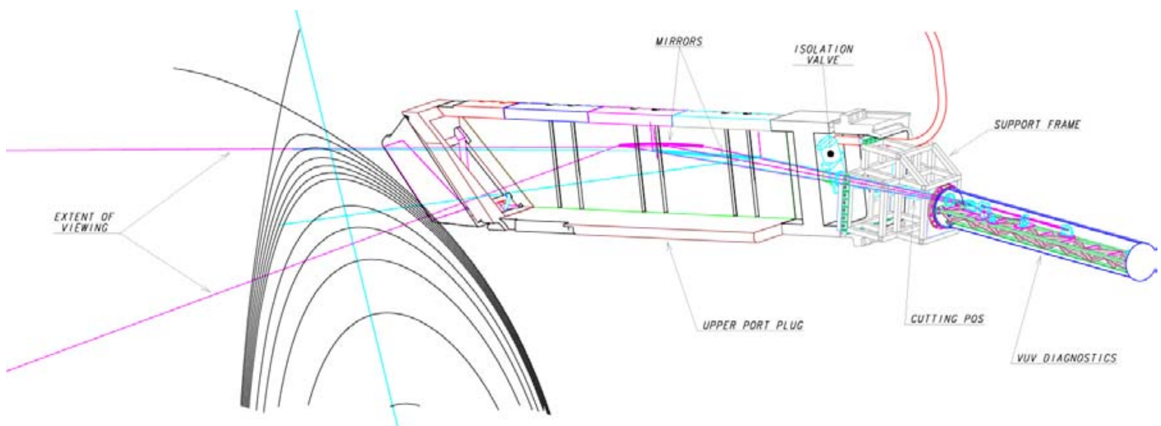


Figure 8.3 – The VUV-imaging at uport#10 based on two large grazing incidence mirrors. The spectrometer frame was inspired in a space telescope frame design.

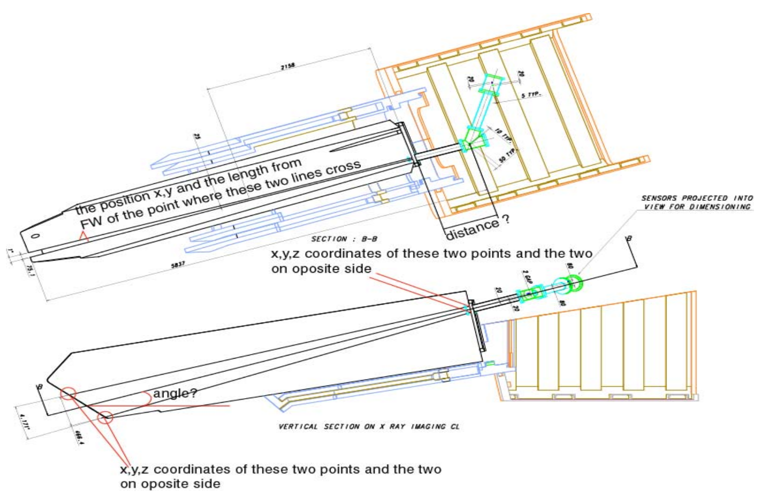
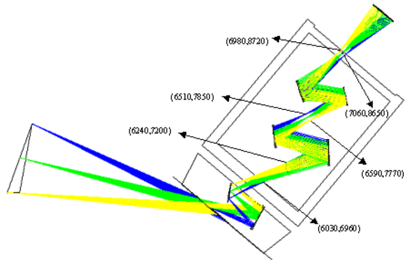
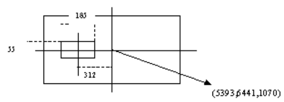


Figure 8.4 – Views from the uport#9 containing the upper X-ray imaging used for the definition of dimensions for neutron flux analysis.



Component	width	height	Focal radius longitudinal	Focal radius transversal	x	Y	z	Angle to x
M1	350	90	950	1100	5873	6441	1070	-29
M2	260	40	INFINITY	INFINITY	5493	6781	1070	170
M3	360	120	1600	1100	6833	7331	1070	2.3
M4	310	70	2600	2600	6103	7551	1070	186.3
M5	250	130	2500	2200	7063	8091	1070	11.6
M6	300	170	1200	1200	6453	8161	1070	198



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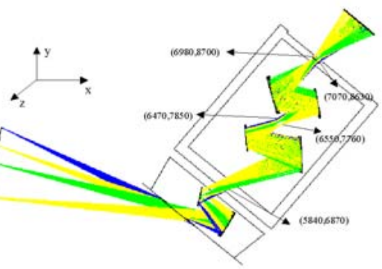

component	width	height	Focal radius longitudinal	Focal radius transversal	x	y	z	Angle to x	Angle to Horizontal plane	Mirror Rotation angle
M1	380	90	950	1100	5833	6391	-135	-31.5	-10.3	-3.5
M2	260	50	INFINITY	INFINITY	5473	6771	-135	169	0	0
M3	500	250	1600	1100	6823	7351	-135	3	0	0
M4	350	70	2600	2600	6093	7581	-135	185	0	10
M5	400	280	2500	2200	7043	8061	-135	9	0	-3
M6	500	250	1200	1150	6443	8171	-135	195	0	7

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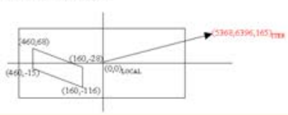


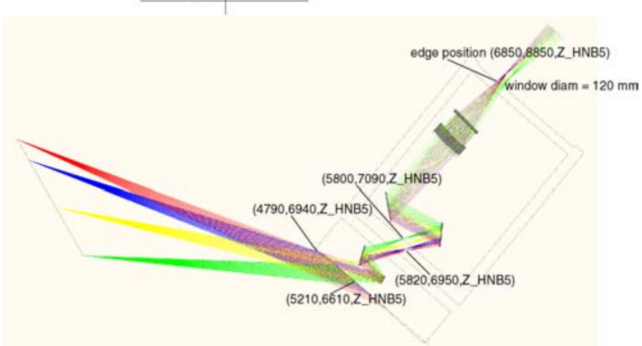
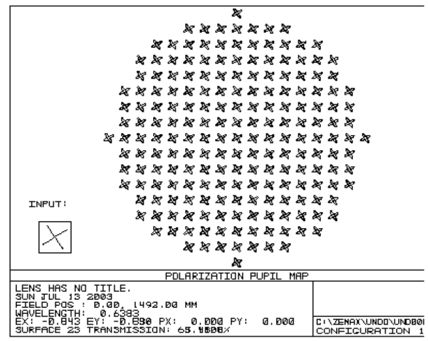


Figure 8.5 – Optical arrangement for the edge CXRS upper and lower systems (top) and MSE at eport#1 (bottom).

Output of pupil polarization map calculation



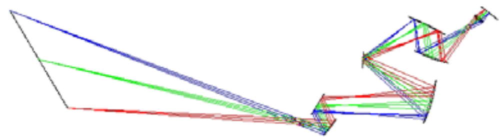


Figure 8.6 - The core MSE optical system in eport#3. In this analysis is quite visible the eliptization induced by the mirrors on the polarization state of the input light.

- Evaluation of the effects that Be and C deposition on the first mirror would produce in the interpretation of the CXRS and MSE data. To that end an analytical model has been developed to compute the phase shift and variation of reflection coefficients for s and p components of the CXRS and MSE light components for a metal-metal interface. Figure 8.8 presents the main results for the CXRS/MSE diagnostic, which show that the Be coatings can introduce a systematic inaccuracy of 5^{o} in the orientation of the MSE Pi component. Similar studies have been made for the pure MSE diagnostic using the HBs and the conclusion is that first mirror coatings may constitute a serious source of inaccuracy calling for real time calibration techniques and on-line mirror cleaning.

8.3. MICROWAVE REFLECTOMETRY

8.3.1. Introduction

The main activities carried out in 2003 were:

- Further studies for plasma position/shape measurements as required for ITER;
- Assessment of microwave and millimeter wave technologies that, besides reflectometry, will also be used by ECE and ECA diagnostics on ITER;
- Continuation of the development of an advanced FM-CW reflectometer (beyond the state of art) capable of performing profile measurements at very high densities/long distances.

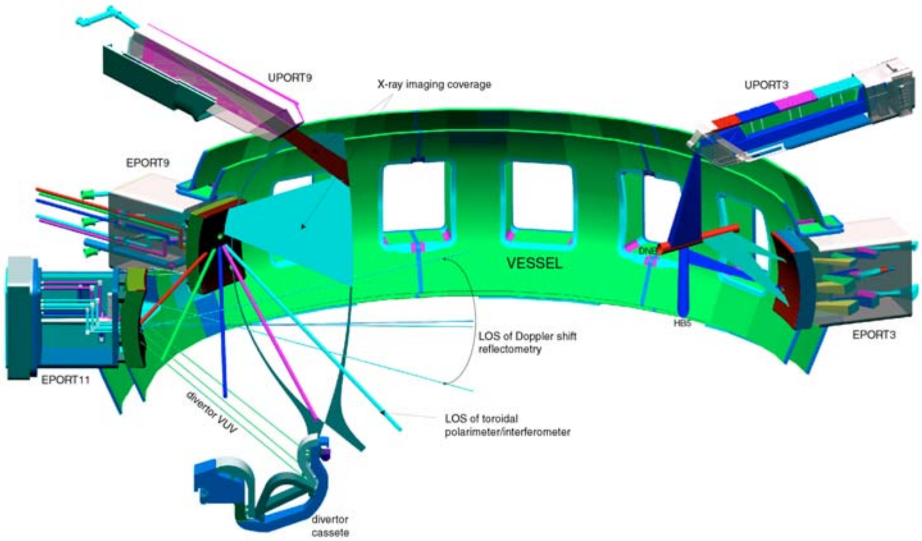


Figure 8.7– General arrangement of some of the ports designed during 2003.

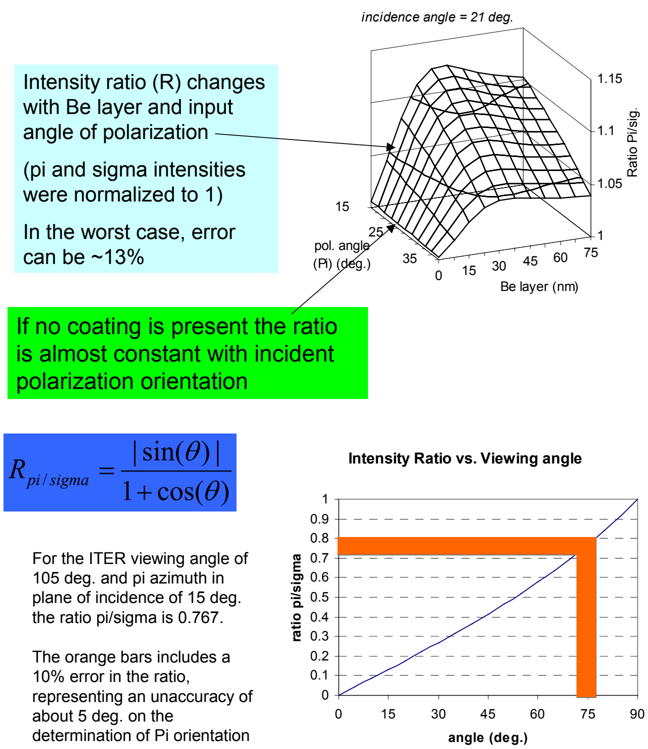


Figure 8.8 - On top: changing of intensity ratio with Be coating thickness on top of a Au mirror. On bottom: representation on an inaccuracy of 10% in the intensity ratio measurements due to an apparent change of Pi polarization direction caused by Be coating deposit.

8.3.2. Position control

The FM-CW reflectometers on ASDEX Upgrade were used to demonstrate the control of plasma position from reflectometry, as required for ITER long pulse operation. It was shown 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. The possibility of using reflectometry for shape control was also considered. The evolution of the separatrix position along the discharge was estimated, simultaneously in the inner and outer midplane, using a scaling relationship between the average linear density and the density at the separatrix. Good results were obtained (typically a total RMS deviation 0.85 cm) for standard H-Mode shots, with type I ELMs, the ITER reference scenario.

Figure 8.9 shows the positions of layers with densities corresponding to several n_{sep}/n_{med} ratios after removal of measurements made during ELM onset and MHD phases (discharge #18352, 1 MA, 2 T, q_{95}=3.22, k=1.717, d=1.52, single null divertor). Burst mode measurements were performed at a 20 ms rate. Superimposed to these curves, in black, is the magnetically inferred separatrix position. The proximity of time traces of the position of different tracked layers indicates the location of the external transport barrier (ETB). A more detailed analysis of those curves suggests an increase of n_{sep}/n_{med} with the increase of n_{med}, in agreement with ASDEX Upgrade team findings. The steeper part of the measured profiles translates into a higher proximity between the plotted curves. Consistently, in both HFS and LFS, after the L-H transition (t~1.85 s) and during the initial density ramp-up, curves corresponding to a n_{sep}/n_{med} ratio of 30% and

40% are closer. Then the density drops with the increase of ELM frequency but ratio at the steep region rises to 40%-50%. The injection of more 2 MW of neutral heating and a strong fuelling gas puff, triggers higher frequency higher density ELMs (reach 5 ms period at t~5 s) leading to an increased density steady state phase. Again, the proximity of the curves suggests an ETB rise to densities corresponding to 50%-60% n_{sep}/n_{med} ratios. During this phase rapid ELM recovery results in oscillations of the positions in the steep gradient region of less than 0.5 cm.

A workbench of integrated tools was developed (presently under test) for the systematic study of experimental and simulated data at all steps of the profile evaluation. These tools, that include a 1D reflectometry simulator adapted to the ASDEX Upgrade geometry, allow sensitivity studies and the experimentation of new algorithms related to the real time use of reflectometry for plasma position and shape control.

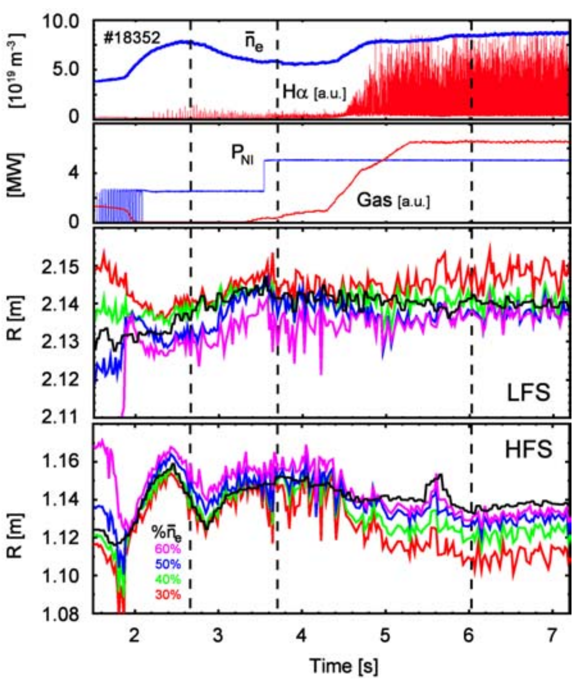


Figure 8.9 – Position of density layers at several n_{sep}/n_{med} values in standard H-mode shot 18352 (magnetic separatrix position in black)

8.3.3. Assessment of millimeter sub-millimeter wave technologies for reflectometry, ECE and ECA diagnostics

8.3.3.1 Introduction

A comprehensive analysis of possible technologies to probe extremely high densities in the ITER divertor region was made. It was considered the availability of microwave sources and relevant electronics as well as transmission lines for reflectometry, ECE and ECA diagnostics.

8.3.3.2 Microwave sources and electronics

a) Frequency range 15 – 300 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. The most probable scenario for the higher frequencies will be the use of multipliers for broadband operation. Heterodyne detection techniques in swept operation will also require the master oscillator to operate at frequencies where broadband phase locked loops or frequency synthesizers can be used (up to 40 GHz).

b) Frequencies above 300 GHz

Difficulty to operate in broadband schemes especially. Moderate bandwidths are possible in the 300 GHz region, whereas the use of narrow bandwidths is the only reasonable option in the upper limit (900GHz). The same strategy of frequency multiplication seems possible for moderate bandwidths and the final multiplier devices are available up to 1THz with reasonable output power.

For moderate to narrow bandwidths the use of fundamental oscillators in the mmW region followed by frequency multipliers is also a good scheme for signal generation above 300 GHz. Phase lock of such generators is possible.

The power which could be generated from a variety of sources is summarized on (Figure 8.10). The near future prediction is based on active multipliers/amplifiers delivering more power than the actual commercially available products, in the frequency range up to 110 GHz, and passive multiplication above those frequencies. The receiver performance is determined essentially by the front-end mixer characteristics (Figure 8.11). Millimeter wave diodes, used in the mixers, are likely to improve in the next few years. However, the actual performance of those devices is not a limiting factor for reflectometry or ECA diagnostics as the main limitation tends to be plasma emission.

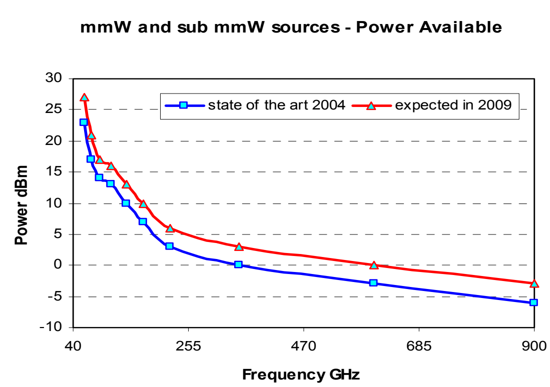


Figure 8.10 – Output power available for millimeter wave and sub millimeter wave sources for broadband or swept operation (moderate band sweep span above 240 GHz).

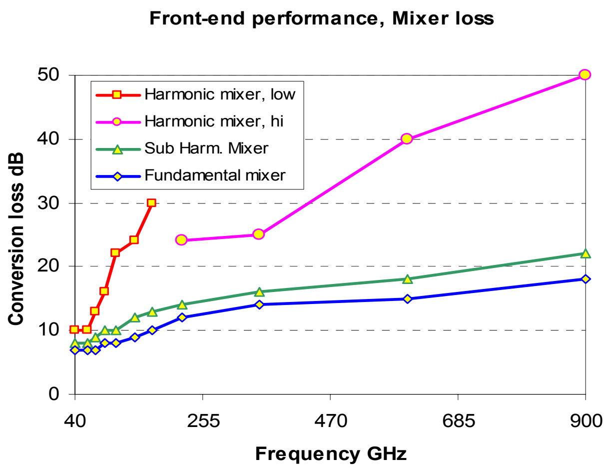


Figure 8.11 - Receiver's front-end performance for various types of devices. Broadband up to 240GHz and moderate band-spans above.

Optical sources down converted to the sub-millimeter region could be a solution for large to extremely large bandwidth sources, but the phase noise of the resulted signal would be extremely poor for broadband swept operation.

Although some recent developments in tuned laser (namely in the erbium doped ring lasers) seem promising they are still far from the desirable figures that would be required for a good sub-millimetre swept heterodyne receiver. On the sub-millimetre bands it is possible to predict the availability of series of moderate bandwidth tuneable oscillators multiplied by diodes in corner cube or other quasi optical structures. Also, there is still the possibility of using BWO tubes up to frequencies above 2000 GHz. However, the possible low phase noise obtainable with today's technology supplants the power advantage of the electron devices at the sub millimetre wave bands.

8.3.3.3 Waveguides

a) Low frequency bands [60-90 GHz]

Fundamental waveguide bands are in terms of the total frequency band required (15-900 GHz) quite narrow. In order to cover until 60 or 90 GHz 4 to 5 bands would be needed. This will mean a bundle of 8 to 10 waveguides and 8 to 10 antennas installed in the ITER divertor. This solution it is therefore not convenient.

A more reasonable approach would be a corrugated waveguide operating on the 50-120 GHz, where the 15-50 GHz frequencies would propagate as in a non corrugated slightly oversized, TE_{11} mode coupling smoothly to HE_{11} as the frequency increase. This requires only two waveguide bundle and two antennas.

On the frequencies we are coupling clearly to HE_{11} polarity control can be done at the quasi optical interfaces by wire grid polarizer while frequency separation can be done using FSS (frequency selective surfaces). On the lower part of the spectrum we have a classical EM microwave design Interface. Some design effort is required to separate the lower part of the spectrum and the quasi optical one. Antenna design requires some effort to result in a meaningful performance in the lower spectrum region.

b) Middle band [120-250 GHz]

Corrugated waveguide designed for the 120 GHz to 250 GHz (or to 300 GHz if corrugation technology-price allows) propagating HE_{11}. Low loss and well known technology. As on the lower bands polarity control can be done at the quasi optical interfaces by wire grid polarizer while frequency separation can be done using FSS. Antennas would not present any complex design problem.

c) Upper band [above 300 GHz]

Above 300 GHz corrugations cannot be machined with a reasonable performance. However, smooth circular waveguides propagating Gaussian beams can be used. Polarity control is assured by wire grid polarizers and frequency selection by FSS. Complex lines may require additional polarizers and beam shapers along the line. This is inherently a low loss line. However such broadband line may not be possible to construct free of resonances. On the other side instruments are likely to have moderate to narrow band-sweep-spans and therefore the design for this spectrum region should start with the waveguide lines and only after a good knowledge of the lines performance in the real scenario the instruments should be designed.

8.3.4. Development of new generation broadband coherent reflectometer

Following the work initiated in 2002, the study of a new generation reflectometer was pursuit aiming to resolve problems that are crucial for ITER due to the longer transmission lines and greater propagating distances in the plasma, increasing significantly signal losses.

Main task carried out were:

- Completion of the conceptual design of the novel reflectometer
- Selection of microwave components for a prototype system.

8.4. ITER NEGOTIATIONS

Prof. Carlos Varandas has attended two meetings in 2003 of the ITER negotiations, as member of the delegation of the European Union.