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Design, laboratory characterization and installation of the multichannel reflectometer's transmission lines at ICRF antenna in Asdex Upgrade

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In order to improve the coupling of the RF power injected to heat the plasma, a detailed knowledge of the plasma density profile in front of the launching antennas is essential. Reflectometry is one of the best candidates to achieve this since it is a non-invasive method, requiring only a limited access space to the plasma, while guaranteeing a very good spatial and temporal resolution. A new multichannel reflectometer is installed inside one of the new ICRF antenna at ASDEX Upgrade (AUG): it consists of three channels that can be switched between 10 antenna pairs with different lines-of-sight (accesses) to the plasma, working in the frequency range 40-68 GHz, using the upper (right-hand) X mode cut-off, with a frequency scan in 10 μs, every 15 μs. The transmission system is composed of standard WR19 waveguides in fundamental mode, and includes DC breaks and low pass filters to reject frequencies of the ECRH systems. WR19 rectangular horns and truncated WR42 waveguide have been used as antennas. All in-vessel components have been tested by pre-installation on a spare Vacuum Vessel Octant and are now fully assembled and tested in AUG. Reflection and transmission coefficient, as well as the coupling between the antennas, have been measured. The results of this measurements, their comparison with the simulations of a full wave code and an estimation of the power level expected at the receiver are reported in this paper.

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1. Introduction

The coupling of the ICRF power to the plasma is strongly dependent on the plasma edge density profile in front of the antenna. For this reason a detailed reconstruction of the plasma profile in the antenna environment with a good spatial and temporal resolution is essential in order to follow its behavior during the ICRF heating phase. Reflectometry is the natural candidate to cover this issue, providing profile measurements of the core and edge plasma density [1], [2], [3] with satisfying spatial and temporal resolution and especially with a limited request for plasma access. One of the two new ICRF antenna at ASDEX Upgrade (AUG) has been equipped with a new multichannel reflectometer [4] with ten accesses to plasma placed within and just outside of the antenna (figure 1 a). Each channel is made of a pair of antennas for launching and receiving the RF signal (bistatic configuration). The reflectometer, born as a collaboration between C.R. ENEA Frascati, IPP Garching and IST Lisbon, will be able, in the beginning with three of the channels fully instrumented, to determine the density profile simultaneously in three different position in front of, or near, the antenna. The completion of the multichannel fast scanning reflectometer is foreseen in the mid of 2015. In vessel components have been already assembled in AUG.

2. The multichannel reflectometer

The reflectometer is working using the X mode right cut-off configuration, given the low density expected ($< 10^{19}$ m^{-3}) in the edge region under study. Considering the relevant plasma scenario, with typical magnetic field and electron densities of AUG in discharge with ICRF, the frequency band that covers the plasma edge to the top of the pedestal was selected from 40 to 68 GHz. The full range scan will be performed in 10 μs with a repetition rate of 15 μs. Such a rapid scan will minimize the phase distortions produced by plasma turbulences. The electronics

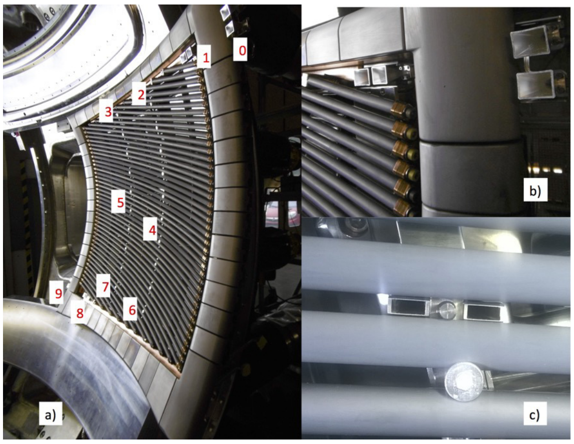

Figure 1: *The ICRF antenna: a) the numbers indicate the reflectometer's accesses (channels). b) Details of upper right corner of the antenna, with channels 0 and 1. c) Details of central access with channel 4*

of the present configuration permits measurements on 3 channels simultaneously. The electronics can be switched to any of 7 pre-chosen accesses without a vessel opening, while the remaining 3 required a reconfiguration of the waveguides inside the vessel (the port only allows for 7 waveguide to be brought outside the vessel). The different accesses to plasma are identified with progressive number (from 0 to 9) representing the different channels (figure 1). A set of TZM rods constitutes the Faraday Shield that will protect the ICRF antenna from the plasma particle flux. Channels 0 and 9, which are outside the antenna as well as channels 1 and 8, which are not cover by the TZM rods, are equipped with rectangular WR19 horns. The available gap between two consecutive rods is 7mm only, which was a challenge for the reflectometer's channels in the middle of the ICRF antenna. After having verified an acceptable value of their coupling with a full wave code, all other channels (from 2 to 7) have been equipped with WR42 truncated waveguide. The electronics is made by a front end, containing the high frequency components, placed near the AUG port in order to reduce the waveguide lengths, and the back end, constituting the IF part, that control the I/Q detector.

3. Transmission lines system

3.1 Realization and installation

The passive components constituting the transmission lines between the electronics and the plasma are DC breaks, low pass filters, WR19 fundamental waveguides, WR42 truncated waveguides or WR19 rectangular horn with gain of 15dBi. All these components have been characterized from the electromagnetic point of view. The DC break, made of kapton, shows negligible transmission losses and a reflection level between 15-20 dB. The low pass filter must protect the mixer from ECRH power. The filter characteristic has been measured up to 160 GHz and guarantees at least 40dB rejection. Concerning the waveguides, WR19 fundamental waveguides have been used, which could be bent to follow the complex path from the vacuum window to the plasma. Waveguides have been split into 3 sequential lengths for assembling purposes. A first set of 14 straight

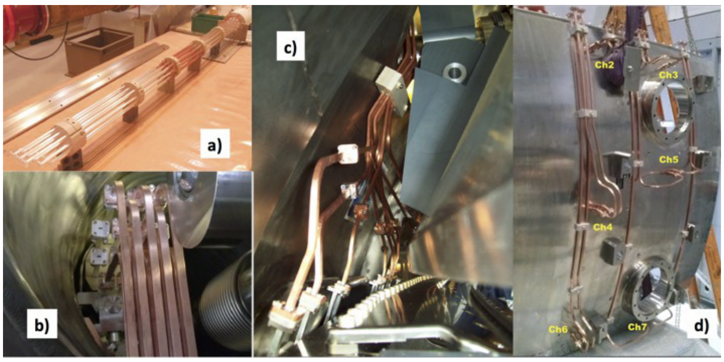

Figure 2: *The different waveguide's section constituting the reflectometer's transmission lines. a) waveguide connecting the vacuum flange to the vessel. b), c) Intermediate waveguide, from vessel to the top of the ICRF antenna. d) waveguide on the back of ICRF antenna.*

pieces, about 1.5 m long are located inside the ASDEX Upgrade Co12 port, running from the vacuum flange to the edge of the vacuum vessel. They have been assembled together in a bundle of a diameter less that 10 cm (figure 2 a) to be inserted from outside through a CF100 vacuum flange. A second set of intermediate pieces continues the connection from the bundle of waveguides to the top of the ICRF antenna (figure 2, b and c). The final set of waveguides, on the back of the ICRF antenna, makes the junction to the horns (figure 2, d). The latter sets have both very different length and shape.

3.2 RF testing

Losses and reflections of all the single sections have been measured after their fabrication and assembly. The whole transmission line, after integration and installation in a mock up of an Octant of AUG, has been tested to check the final performances. These measurements were performed on a reduced frequency band (40-60) using a U-band source of small size assembled at AUG laboratories for this purpose. The total loss measured in the different channels is reported in figure 3

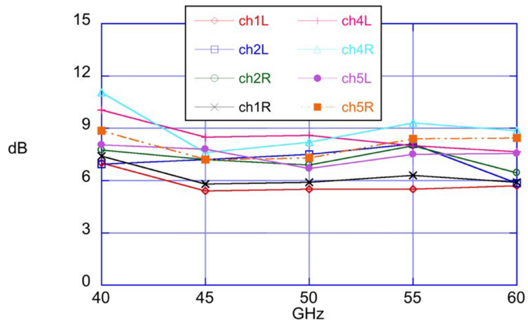

Figure 3: *Measured losses after installation in the octant of the transmission lines of the two antenna (called Left (L) and Right (R)) for some of the different reflectometer's channels*

The spread of the losses level between the different channels is mainly due to the difference in length, which can be up to 1 meter. The return loss has been measured for all transmission lines: it remains around 15-20 dB for all channels, dominated as expected by the reflection of the DC breaks, since the filter was not connected to the system.

4. Transmission lines characterization

4.1 Coupling

After the installation of the system in the mock-up octant, the level of coupling has been assessed, in order to confirm the compatibility of the signal level reaching the mixer and to evaluate the impact of multiple reflections. The test was done placing a stainless steel plate in front of the horns of channels 4 and 5 (truncated WR42 waveguides) and 8 (WR19 rectangular horn). Measurements were performed with the metallic plate moved back from the horns in a controlled way, while the power was measured for all the different position of the plate at few fixed different frequencies. Using a full wave code (the "integral solver" of CST Microwave Studio, computing the current on the conducting surface rather than the field), a simulation reproducing the entire set up has been carried on. The integral solver uses a monochromatic excitation, so the frequency range was sampled and discrete frequency points computed separately. The results of the comparison between measured and simulated data are reported in figure 4. The agreement between the simulations and measurements is good. The effect of multiple reflections introduce a modulation visible

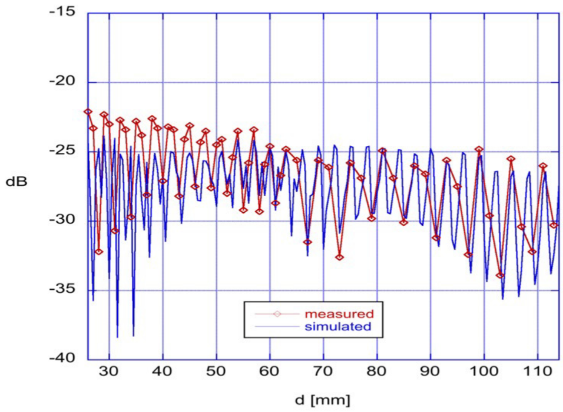

Figure 4: *Comparison between measured and simulate amplitude coupling at 50 GHz for channel 5 (WR42 truncated waveguides)*

on the amplitude data shown: when in operation, density fluctuation will reduce the coefficient of the first reflection, but will reduce the multi reflection effect furthermore, presumably attenuating the modulation. Since at this stage of work it was not possible to acquire phase data, the simulations have been used to also evaluate the distortion of the phase signal, affected as well by the modulation. It was observed that the discrepancy between the straight line expected in an ideal case and the simulated phase data is of the order of 20-30 degrees, corresponding to an error in the position determination of 1mm. Given the mechanical constraints, it was not possible to avoid the presence of these reflections, thus the strategy to deal with the distortion of data is to face it during data analysis. Different techniques have been developed in the last years in order to minimize the effect of multiple reflections and those based on time-frequency tomography seem to give good results [5].

4.2 Power budget

A rough estimation of the signal level that could be expected at the receiver had been performed during the design phase of the new reflectometer system.

Table 1: *Evaluation of the signal reaching the receiver for channel 4, equipped with WR42 truncated waveguides. The characteristics of the transmission lines components are reported in table*

GHz	*Multiplier* [dBm]	*WG(meas +sim)*	*Vacuum window*	*Coupling*	*Isolator*	*Mixer*	*Filter*	*Signal@ receiver*
40	15.6	29.2	0.8	34	2	6.4	2	-58.8
45	16.5	23	0.8	30	2	5.3	0.7	-45.3
50	16.8	23.1	0.8	28	2	5.2	0.5	-42.8
55	17.4	23.6	0.8	25	2	6.4	0.8	-41.2
60	16.9	22.2	0.8	27	3	5	1.2	-42.3
65	10.2	22.1	0.8	27	4	6.4	1.2	-51.3
68	11	22	0.8	28	5	12.5	1.2	-58.5

Measured and simulated data, as well as the data of the electronic components, have been used to update this estimations and to obtain a more precise prediction. This evaluation has been made using the power provided by frequency multipliers and losses of the transmission lines components. A worst case scenario has been considered, using higher loss channels. Nevertheless, it is worth noting that the expected power foreseen at the receiver is within the detectable value of -60dBm with a good margin in the frequency range 45-65GHz, while at the extrema of the frequency band we are near the limit of the instrument's sensitivity.

5. Conclusion

The transmission lines of the multichannel reflectometer, designed to provide the density profile in the environment of one ICRF antenna at AUG, have been realized, pre-installed and extensively tested in an octant mock-up and installed in ASDEX Upgrasde. Their transmission and reflection coefficients have been evaluated. The measurements guarantee that the realization, integration and installation of the system have been properly done. The coupling between the horns has also been measured: these data, together with the simulated ones and those of the electronic components, confirm that the signal at the mixer is actually within the expected detectable values, with marginal values only at the extrema of the frequency band for channels with higher losses. Simulations of the horn's coupling has been performed and amplitude data are in good agreement with the simulated ones. Since at this preliminary stage of the work it was not possible to measure the phase data of the signal, simulation were used to check the phase distortion produced by multiple reflections. The foreseen distortion should correspond to an error in the position's determination of about 1 mm.To minimize the effect of multiple reflections on phase data, time to frequency tomographic data analysis technique are being implementing.

Acknowledgments

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