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LOWER HYBRID WAVE COUPLING IN TORE SUPRA THROUGH MULTIJUNCTION LAUNCHERS

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LOWER HYBRID WAVE COUPLING IN TORE SUPRA THROUGH MULTIJUNCTION LAUNCHERS

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1. INTRODUCTION

The TORE SUPRA Lower Hybrid Current Drive experiments (8 MW/ 3.7GHz) use large phased waveguide arrays (4 rows of 32 waveguides for each of the two "grills") to couple the waves to the plasma [1].These launchers are based on the "Multijunction" principle which allows them to be quite compact but needs to be fully assessed for the design of efficient multi-megawatt antennas in NET/ITER.

2.METHOD OF ANALYSIS

A detailed experimental study of LH wave coupling to the TORE SUPRA plasma has been carried out from the analysis of the RF measurements available at the input of each module. The power in each module is first divided poloidally through a vacuum hybrid junction and two 4-waveguide E-plane junctions. Two rows of 8 modules are juxtaposed toroidally to form one launcher. The power and phase in each module can be varied independently thus allowing the launched spectrum to peak between $n_{//} \approx 1.5$ and $n_{//} \approx 2.3$.

Instead of comparing the power reflection coefficient in the individual modules for various phasing conditions, we have measured the plasma loaded scattering matrices S which, by definition, link together the incident and reflected fields. The scattering matrices contain the intrinsic features of the plasma loaded antenna, independently of the feeding conditions.To determine the 8*8 elements of the complex matrix S, it suffices to consider 8 independent arrangements of incident electric field phases, at stationary and reproductible plasma conditions, and to measure the corresponding reflected field.

In the framework of the 2-D linear coupling theory of the "grill" [2] and using the SWAN code [3], S has been numerically calculated in various edge plasma conditions (edge electron density and edge density gradient). Comparison with experimental results has been made possible since the internal power splitting of each module and the gaps (1mm) between adjacent modules have been fully modelled. The internal power splitting model has been successfully compared to the measurements performed on a test module [4].

3.EXPERIMENTAL RESULTS

3.1 Coupling results

The dominant scattering coefficients of the waveguide arrays have been obtained in various edge plasma conditions. The electron temperature and density of the plasma facing the LH antenna have been investigated by means of 3 Langmuir probes toroidally spaced in the equatorial plane. Figure 1 depicts the case where the measured edge plasma density was kept constant well above the LH cut-off density , i.e $n_e \approx 1.4 \times 10^{18}\ m^{-3} \pm 20\%$. An excellent agreement has been obtained between all these measured scattering coefficients, including their phases, and those deduced from the linear coupling theory. The symmetry of the scattering matrix (S(i+1,i) = S(i,i+1)), which is an implication of the field reciprocity theorem, is verified. Moreover, the dispersion (if any) enables us to estimate the relative errors of the electric field measurement, which in the worst cases are ± 10% and ± 20° respectively on the amplitude and phase.

Such agreement gives us strong confidence in the determination of the power spectra radiated by the multijunction antennas. Figure 2 shows the deduced experimental asymmetric power spectra obtained with phase shift, $\delta\Phi$, between the juxtaposed modules of -90°,0°,+90°.

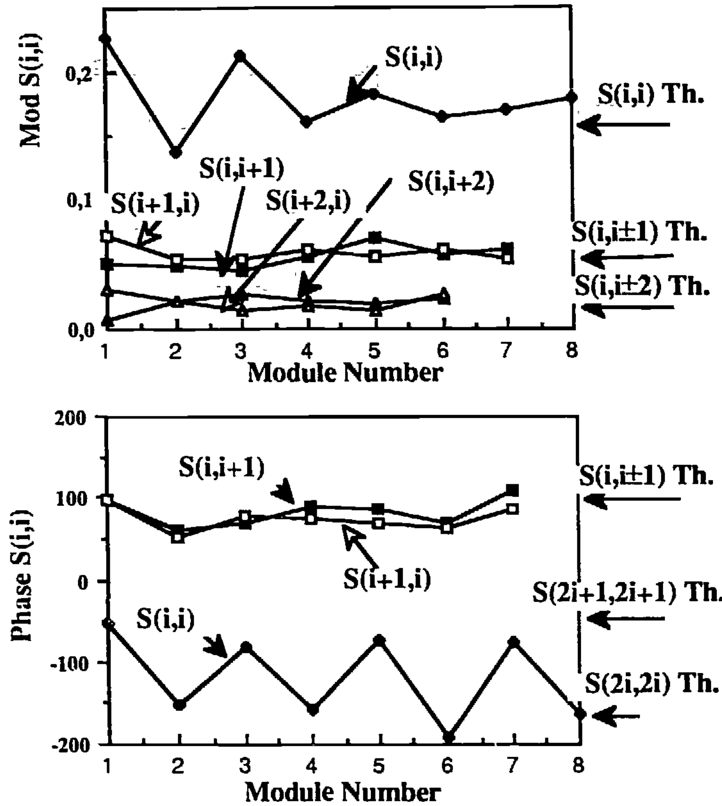


Fig. 1: Amplitude and Phase of the experimental S(i,j) coefficients versus the module number i . The theoretical calculations assumed an edge electron density of n_e = 1.4 x 10^{18} m^{-3} ($n_e \approx 7$ x n_{co}) and an electron density decay length of 2cm according to the Langmuir probe measurements.

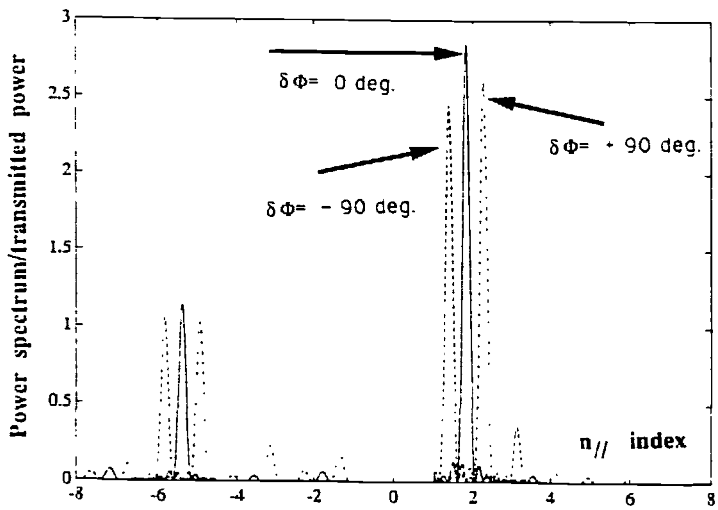
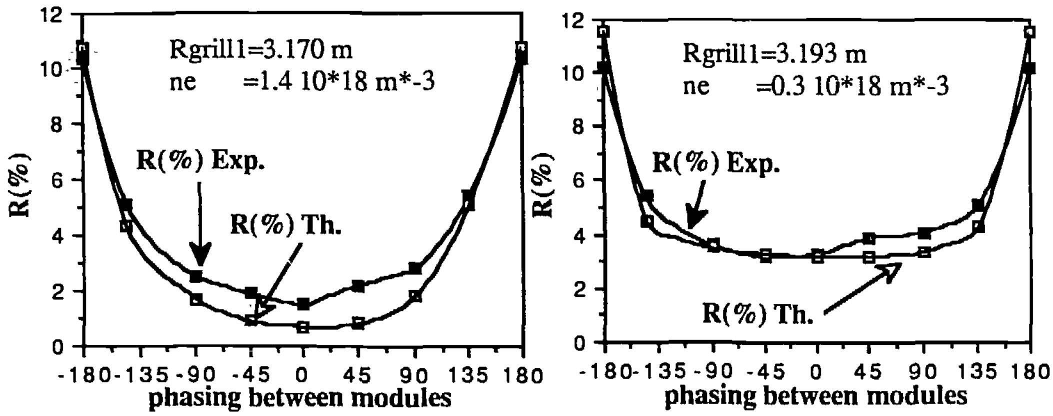


Fig.2:"Experimental" radiated spectra. $\delta\Phi$= -90°, 0°, +90° respectively $n_{//peak}$=1.4, 1.8, 2.3.

Figure 3 shows that average power reflection coefficients of a few percent (2 to 4 %) have been obtained in a large range of edge plasma densities (0.3 x 10^{18} $m^{-3} \leq n_e \leq$ 1.4 x 10^{18} m^{-3}) and phasing between modules ($\delta\Phi$= -90° to +90°). The experimental data are in good agreement with the theoretical simulations performed with the measured edge plasma density.

To conclude, it should be emphasized that figures 2 and 3 illustrate that flexibility in $n_{//}$ is obtained in a large range of edge plasma densities (or antenna positions) while preserving an optimum behaviour of the antenna [5].

Fig. 3



3.2 Density and temperature modification of the scrape-off-layer

During current drive experiments at high RF power, strong outgassing of the antenna (up to 2 x 10^{20} particles/second -fig. 4-a) may occur in not fully conditioned operations. Consequently an increase of the electron density, up to 50 %, was measured at the grill aperture (fig. 4-b). This is consistent with a flattening of the electron density profile measured with the I. R interferometer. By ramping the RF power launched by one antenna between 0 to 2.8 MW, the scrape-off layer facing the antenna is significantly heated at a rate, normalized to the edge electron density, of 5 eV / MW / 10 ^{18} m^{-3} (fig. 5). Anyway, we have confirmed that in the presence of LH power the observed edge density and temperature perturbation do not modify the good coupling characteristics of the antennas.

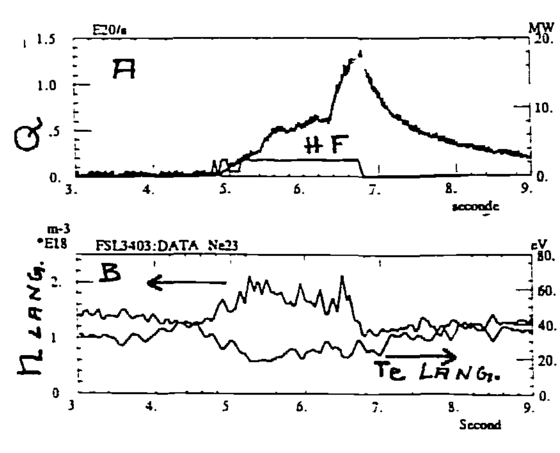


Fig. 4:Gas injection from LH antenna

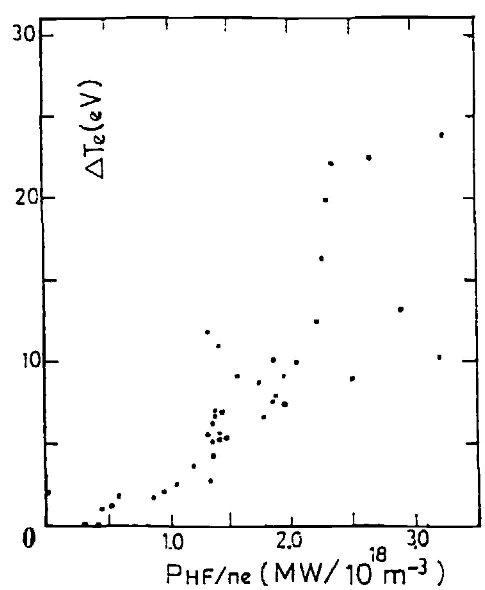


Fig. 5: S.O.L. heating by LH power

3.3 High power experiments

The good behaviour of the TORE SUPRA antennas observed at low transmitted power ($\leq$ 5MW/m^2) is still obtained at higher power levels. More than 3 MW have been transmitted separately by each antenna. Fig 6 confirms that the power reflection coefficient and its phase measured in the central modules are kept constant (R $\leq$ 3%) at power densities up to 45MW/m^2.

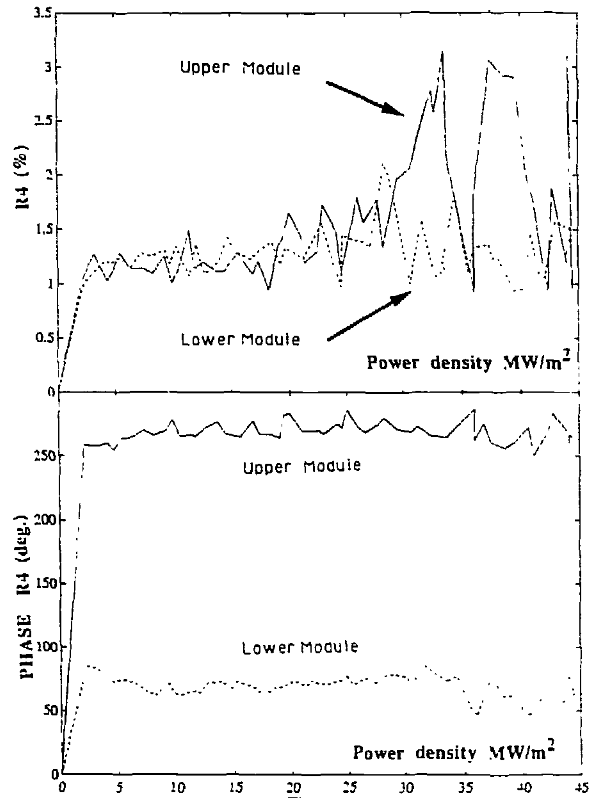


Fig.6: Power reflection coefficients and phases - central modules- versus the injected power density (MW/m^2). The phases remain constant indicating that RF breakdown in the modules have not occured.

4. CONCLUSION

Extensive coupling measurements have been performed to study the Radio-Frequency characteristics of the plasma loaded multijunction antennas.The experimental data have been related to the output of the linear coupling theory which, in its advanced stage, takes into account the specific features of the compact launchers. The measurements, scattering matrices and power reflection coefficients, are in perfect agreement with the theoretical simulations performed with the measured edge plasma density. Our analysis leads to the determination of the $n_{//}$ radiated spectra. We demonstrate that the $n_{//}$ flexibility is obtained in a large range of edge plasma densities (or antenna positions) while preserving an optimum behaviour of the antenna. Finally, the "Multijunction" launcher has proved to be able to transmit high RF powers since power densities up to 45MW/m^2 have been reached with good linear coupling characteristics and spectrum control.

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