

## Validation of Lower Hybrid coupling codes (Brambilla, GRILL3D-U, TOPLHA) with the FTU conventional grill

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### Introduction

The LH coupling understanding started many years ago and developments in the launcher design were continuously pursued in view of ITER severe edge conditions. The excitation of LH waves by means of a phased waveguide array was initially proposed in 1974 by Lallia [1]. A systematic study of the coupling problem related to this launching structure was firstly done by Brambilla in 1976 under the so-called *grill theory* [2]. Subsequently, more detailed analyses were performed [3, 4, 5], still adopting several approximations in order to simplify the problem, such as the absence of mode conversion and 2D antenna models. The following studies developed more sophisticated models [6, 7], for instance taking into account new antenna concepts, fast wave excitation, finite poloidal dimensions, etc.

At the same time, numerical tools implementing theoretical models were developed; they were essentially based on mode matching technique, single-pass approximation and a slab plasma model. From the antenna viewpoint, the first codes could handle very simple antenna geometries [8, 9], which then considerably increased in complexity [10, 11, 12]. Lately, due to remarkable developments in computational electromagnetic techniques, new codes, totally or partially based on full-wave antenna solvers, appeared too [13, 14].

This paper validates three LH coupling codes based on different solving techniques: TOPLHA, GRILL3D-U, Brambilla code. They have been run to compute the coupling between the LH waves, launched by a row of the independently phased waveguide array antenna (*conventional grill*) [15], and some FTU plasmas.

TOPLHA and GRILL3D-U have been already compared with another well-established code, i.e. ALOHA [14], in the frame of the EFDA task HCD-08-03-01, where the LH antenna, proposed for ITER, was used as benchmark [16]. Furthermore a validation of TOPLHA, GRILL3D-U and the Brambilla code has been recently done as regards to the FTU conventional grill in terms of average reflection coefficients [17]. In this paper a more detailed analysis is presented by comparing simulated curves with experimental data, that refer to the reflection coefficients effectively measured at the antenna mouth by built-in directional couplers.

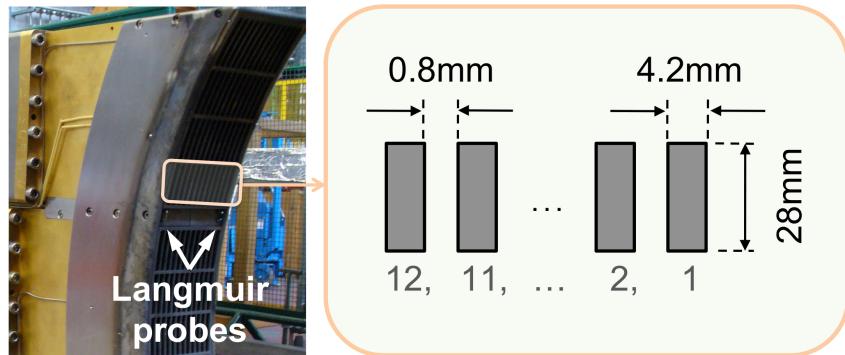


Figure 1: Waveguide dimensions.

## Tools and benchmark description

The Brambilla code, GRILL3D-U and TOPLHA are rather different codes, conceived to predict the performance of plasma loaded antennas in the LH range of frequencies.

TOPLHA [13] is an advanced, recently developed, LH coupling code, based on boundary-value problem with the adoption of a triangular cell-mesh to represent the relevant waveguide surfaces. GRILL3D-U [12] is an advanced, well-established code that formulates the problem in terms of rectangular waveguide modes, considering waveguides with finite cross-section in both directions. Finally, the Brambilla code [2] is a very simple tool that cannot take into account realistic 3D antenna geometries, but it just implements the grill theory.

These codes have been benchmarked with reference to a row of the LH conventional grill antenna installed in the Frascati Tokamak Upgrade (FTU), a circular cross-section tokamak with high toroidal magnetic field. Each row of the grill consists of 12 independently phased active waveguides, designed to work at 8 GHz (cut-off density  $\cong 0.8 \times 10^{18} \text{ m}^{-3}$ ) and fully monitored in terms of direct and reflected powers. The choice of the row used for the code validation was driven by several reasons like the tube reliability, the attempt of avoiding rows with stronger poloidal curvature and the availability and closeness of Langmuir probes. The relevant waveguide dimensions, as seen from the plasma, are reported in Fig. 1.

Simulations can be grouped in two sets: the first one has toroidal magnetic field  $B_0 = 5.9 \text{ T}$  and waveguide phasing  $\Delta\phi = 90^\circ$ , while the second one presents  $B_0 = 7.1 \text{ T}$  and  $\Delta\phi = 75^\circ$ ; the peak  $n_{\parallel}$  of the two cases are approximately equal to 1.88 and 1.56, respectively. Each set of simulations consists in ten different plasma profiles with edge electron density adaptively varying in the range  $[0.8 \div 8] \times 10^{18} \text{ m}^{-3}$ . Density profiles have been inserted as input in the simulations in the form of parametric curves according to code constraints. In details a linear profile has been used for the Brambilla code and a parabolic one for GRILL3D-U and TOPLHA

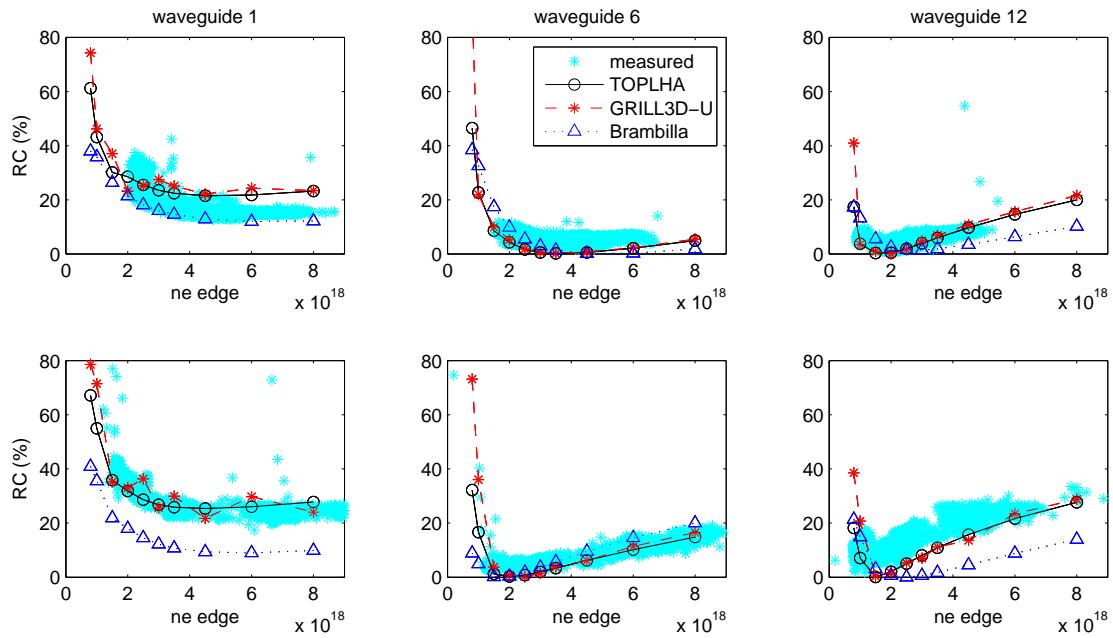


Figure 2: Reflection coefficients for the outer left, central and outer right waveguides in the 90° (top) and 75° (bottom) phased row of the FTU LH conventional grill.

(that can also handle linear and user-defined profiles).

The values of the parameters defining each density profile have been estimated by means of a curve fitting over the measured density profiles, taking into account the launcher position. In particular the FTU shots #27100, #27566 and #27578 have been used for the 90° phasing case, while shots #26562, #26476 and #26470 for the 75° phasing case. They have been chosen among the benchmark-relevant shots according to the availability of the density profile measurements and the performance of the LH pulse.

Further information on codes themselves and on their benchmark can be found in [17].

## Results

From the measurements of forward and reflected powers, the reflection coefficient (RC) of each output channel of the row has been calculated, associated with the relevant edge density (i.e., the value measured by the closest Langmuir probe at the same time) and plotted in the form of a cloud of points together with the curves predicted by the coupling codes. For sake of brevity, only the most significant pictures have been reported here (see Fig. 2), namely those regarding the two outermost waveguides plus one located in the middle of the row. It can be noted that the predictions of the Brambilla code are reliable for the central waveguide of the grill, but they generally fail for the side waveguides.

## Conclusions

A row of the FTU LH conventional grill has been simulated in terms of RF performance for several plasma profiles and two different waveguide phasings by means of the Brambilla code, GRILL3D-U and TOPLHA. The reflection coefficients predicted by the codes at the antenna mouth have been compared to the measured ones.

Very good agreement with the experimental data exists for the most advanced numerical tools, namely GRILL3D-U and TOPLHA. As far as the predictions of the Brambilla code are concerned, their reliability is good in the middle of the grill, but it deteriorates as approaching the outer waveguides of the row.

As a next step the comparison can be extended by including other coupling codes.

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