Microwave probe diagnostic for the lower hybrid four-way-splitter antenna on Alcator C-Mod

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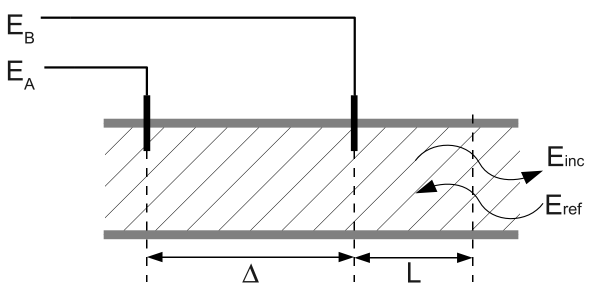
Abstract

The new lower hybrid launcher (LH2) of the Alcator C-Mod tokamak is based on a novel 4-way-splitter concept. A diagnostic based on the microwave probes concept [Jacquet et al. 1997] has been installed to verify the LH2 design and study the physics of LH wave coupling. A total of 32 dedicated probes measure the forward and reflected power in a carefully selected set of the active and passive waveguides of the LH2 grill. A new technique for measuring the density profile in front of the launcher is proposed, which can be performed without relying on other diagnostics.

A new lower hybrid phased waveguide array launcher (LH2) has been recently installed in the Alcator C-Mod tokamak. The antenna operates at 4.6 GHz and is based on a novel four-way-splitter concept [1], which evenly splits the microwave power in four ways in the poloidal direction. The launcher is made of a stack of 16 four way splitter modules, resulting in a grill of 16x4 waveguides. This design allows the simplification of feeding structure, while keeping the flexibility of launched toroidal spectrum.

The LH2 antenna has been designed based on the LH wave linear coupling theory [2]. The TOPLHA and ALOHA codes predict that the evenness of power splitting in the poloidal direction, will be affected by poloidal uneveness of the density profiles in front of the launcher 2. Nonetheless, good



$$E_{\text{inc}} = \frac{-(E_A e^{-iK\Delta} + E_B)e^{-iK(\Delta+L)}}{1-e^{-2iK\Delta}} \quad (1)$$

$$E_{\text{ref}} = \frac{-(E_A e^{iK\Delta} + E_B)e^{iK(\Delta+L)}}{1-e^{2iK\Delta}} \quad (2)$$

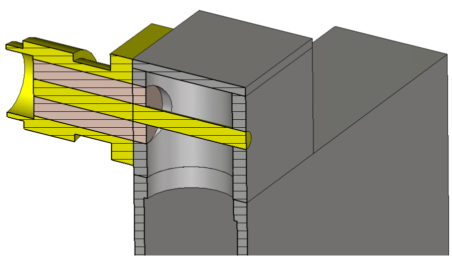


Figure 1: Schematic of the microwave diagnostic; Equations for calculating incident and reflected waves; CAD drawing showing a cutout of the probe assembly

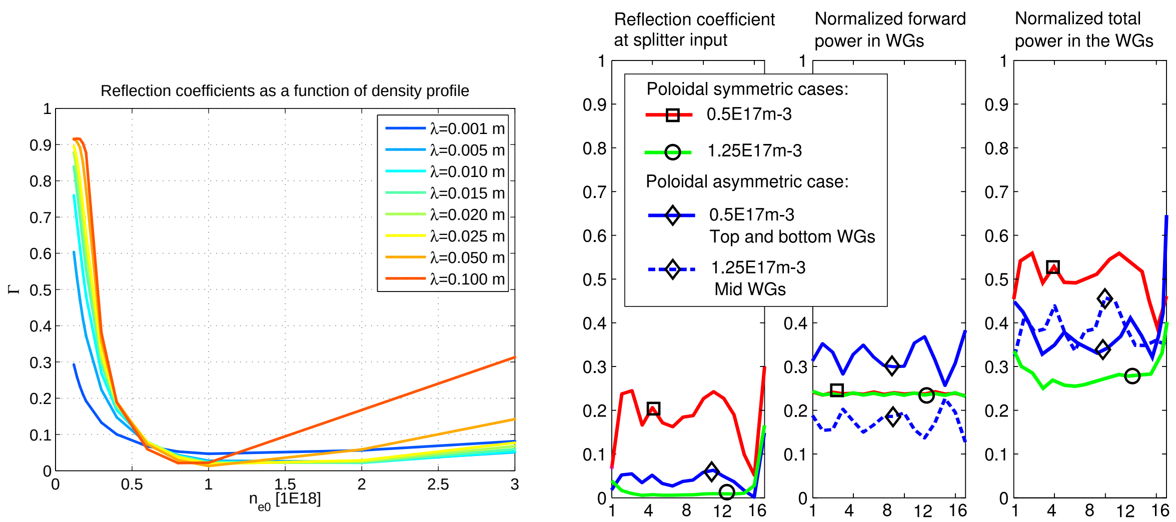


Figure 2: A) Simulated average reflection coefficients for 90 degrees phasing as a function of n_{e0} for different values of λ; B) Reflection coefficient at the input of the 4-way-spitters in the case of even and uneven poloidal plasma density profiles.

plasma coupling and a clean $N_{||}$ spectrum over a wide range of edge density profiles are expected [3]. The assessment of the performance of the LH2 design and the direct benchmarking of the 4-way-splitter concept requires measurements of the antenna-plasma coupling. For this purpose, a diagnostic composed of a set of 32 microwave probes [4] was designed to measure the forward and reflected waves at the grill mouth. These measurements are also planned to be used as a part of the coupler protection system. In addition, the LH2 launcher is equipped with a total of six Langumir probes, and a X-mode reflectometer system for measuring the density profile in front of the launcher.

Microwave probes are installed in the waveguides of the two centermost columns of waveguides and on every other waveguide at the bottom row of grill. In each of the monitored grill waveguides, two probes displaced by one quarter of the guided wavelength λ_g sense the wave field in the waveguide (Fig. 1). The forward and reflected waves can then be deduced according to Eq. 1 and 2, where K is the wavevector of the TE_{10}, and L is the location of the reference plane. Two of the 8 dummy columns are also monitored by one probe each, which is located at $\lambda_g/4$ from the short at the end of the waveguides.

Microwaves are coupled to the probe through a small circular coupling hole located on the narrow side of the waveguides. The central conductor of the probe is welded to the opposite side of the probe housing (Fig. 1). This design allowed good reproducibility of the probe coupling performance ($\approx -65 \pm 2$ dB). Silicon-Dioxide (S_iO_2) cables are used in-vessel to ensure low losses and the stability of phase with respect to temperature variations. The phase and amplitude of each probe signal is finally measured with off-the-shelf homodyne IQ detectors and are

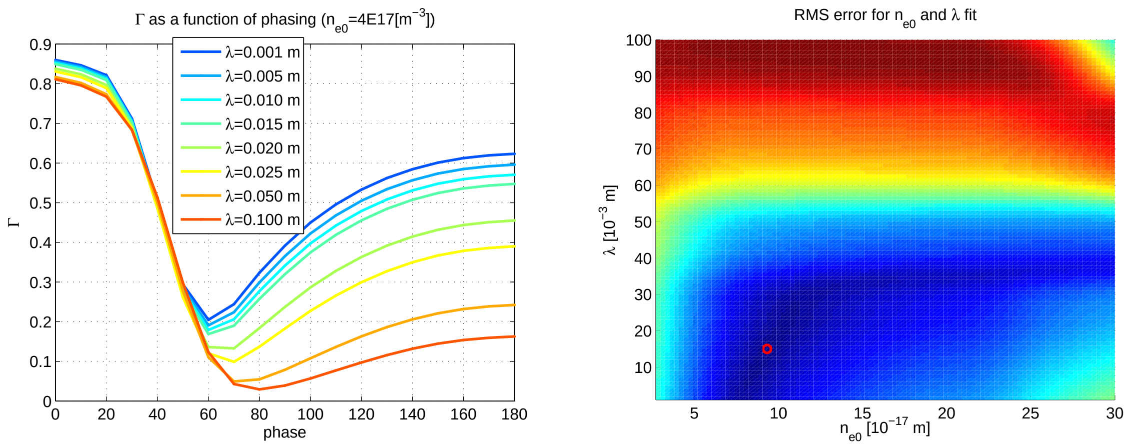


Figure 3: A) Simulated average reflection coefficient as a function of the antenna phasing for different values of λ; B) RMS error of the fitting procedure as a function of the fitting parameters n_{e0} and λ.

digitized at 250 KHz.

From a physics standpoint, the microwave probes diagnostic allows a detailed study of the LH wave coupling problem. The coupling efficiency strongly depends on the parallel wavenumber $N_{||}$ of the launched wave, the plasma edge density n_{e0} and the plasma density scale length $\lambda = n_{e0}/\frac{\partial n_e}{\partial r}$ at the mouth of the LH antenna [2]. Figure 2 shows the predicted reflection coefficient for LH2 as a function of n_{e0} and λ for 90 degrees phasing. Currently, it is common practice to use the ambiguity of the edge density profile to make coupling simulations fit to the experimental measurements [5, 6, 7, 8, 9, 10]. In C-Mod, a SOL X-mode reflectometer [11] will be used to measure the actual density profile in front of the launcher at three poloidal locations. The availability of accurate density profile measurements will finally eliminate these free parameters and enable a self-consistent validation of the LH coupling codes. In the experiments, to study coupling as a function of the SOL density profile, the radial positioning of the launcher behind the limiters, gas puffing, and radial movement of the plasma column will be used. Also, Langmuir probes of different length (1 mm and 2 mm) will give a crude estimate of the density and its gradient at the grill mouth.

In addition, the idea of a new technique has been developed for measuring the density profile in front of the launcher, without relying on other diagnostics but the microwave probes themselves. In this technique the phase of the LH waves is quickly swept while the plasma parameters are kept constant. Under the assumption that linear theory holds true, the density profile can be inferred by the least square fitting of the measured reflection coefficients to the ones predicted by linear coupling theory (Fig. 3A). As an example, lets consider a conventional linear density model with two parameters to be determined: the edge density n_{e0} and the density scale length λ. The ALOHA code has been used to compute the plasma impedance for the complete set of density profiles in the range $1.2 \times 10^{17} < n_{e0} < 30 \times 10^{17} m^{-3}$ and $0.1 < \lambda < 10cm$. Figure 3B shows a plot of RMS error of the fitting procedure if an ideal linear density profile with ne0=9E17 [m-3] and =15E-3 [mm] was to be measured, thus giving an idea of the sensitivity of this method. For this example a phase scan between 50 and 145 degrees has been considered, which would keeping the reflection coefficient in the experiment within acceptable limits. The average density profile can be inferred by considering the average reflection coefficients of the whole antenna. However, for the specific case of LH2, this technique can be used to deduce the density profiles at four poloidal locations using measurements from the RF probes located on columns 8 and 9 of the LH2. The X-mode reflectometer will measure the density profile in front of the launcher at three poloidal locations and will be used to validate the phase scan method. If successful, this technique could be used routinely at the beginning of every LH shot and may be the building block for a phase feedback control system which minimizes reflection.

The microwave probes diagnostic will also offer a unique opportunity to study coupling at high power, a regime where linear coupling theory is known to break down [2]. It has been conjectured that this is due to the effect of ponderomotive forces on the edge plasma density, however experimental observations are often contradictory and a definitive theoretical model in this regime is still missing [2, 7, 10].

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