Coupling of LH waves with four-way-splitter antenna on Alcator C-Mod

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The new LH antenna on Alcator C-Mod is based on the innovative 4-way-splitter concept and its performances need to be assessed. High reflection coefficients ($\gtrsim 20\%$) have been a long standing issue for Alcator C-Mod LH systems. LH wave coupling at high power is non-linear and still poorly understood.

Outline:

1. The new C-Mod LH antenna
2. Performance assessment with RF probe diagnostic
3. Characterization of antenna coupling
4. Summary and on-going work
New C-Mod LH antenna is based on 4-way-splitter modules

- 4.6 GHz, 16x4 grill (60x7mm WGs)
- Radially movable grill
- Fixed private limiters

- Poloidal splitting at front of the launcher
  - Simplified low loss feeding network
  - Flexible $N_{||}$ spectrum
  - Directivity and coupling resilient to uneven poloidal plasma load

![Image of the LH antenna](image-url)
RF probe diagnostic measures antenna performances

Phase and amplitude of forward and reflected wave are deduced measuring total wave field in the waveguide at two locations

\[ E_{\text{inc}} = \frac{E_A + iE_B}{2} \]

\[ E_{\text{ref}} = \frac{E_A - iE_B}{2} \]

RF probes arrangement:
- Toroidal array at the bottom of the coupler
- Poloidal arrays at columns 8 and 9

Langmuir probes and X-mode SOL reflectometer measure the edge density
Clean launched spectrum was confirmed by RF probes.

Power spectrum for 70 deg phasing at $t=0.7\,\text{s}$

- Graph showing power spectrum with RF probes measurement and Command.
- Phase [deg] vs. Time [s] graphs for different cases.
Poloidal power splitting depends on plasma shape

Dependence on plasma loading was expected since design stage. Intentional plasma vertical displacement highlights how the 4-way-splitter redistributes the power.

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.74</td>
<td>4-way-splitter input</td>
</tr>
<tr>
<td>0.92</td>
<td>Probes row A</td>
</tr>
<tr>
<td>1.00</td>
<td>Probes row B</td>
</tr>
<tr>
<td></td>
<td>Probes row C</td>
</tr>
<tr>
<td></td>
<td>Probes row D</td>
</tr>
</tbody>
</table>

Net power (column 8)
Coupling agrees with linear coupling theory, provided density profile has a millimetric vacuum layer.

The reflection coefficient increases at higher phasing, suggesting that the waves tunnel through a vacuum layer.

Does this vacuum gap really exist?

LH cutoff density
2.6E17 [m$^{-3}$]

Coupling simulation
with vacuum gap

Coupling simulation
without vacuum gap
Density profiles from newly installed reflectometer support vacuum layer theory

Preliminary SOL reflectometer measurements show evidence of millimetric vacuum layer, as anticipated by coupling simulations.

When using reflectometer density profiles, simulations agree within few % with the measured reflection coefficient. For this shot $\Gamma \approx 26\%$. 

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Summary and on-going work

- RF probes were used to validate 4-way-splitter design
  - Verification of launched spectrum
  - Characterization of power splitting

- Compared coupling results with linear coupling theory
  - Agreement was found provided vacuum layer is present in the model
  - SOL reflectometer measurements provide evidence for vacuum layer

- On-going work
  - Origin of vacuum layer is not clear
  - Preparations for non-perturbative very low power (Watt level) experiment to see if we can recover the coupling expected in absence of vacuum layer
  - Working on several ideas to improve coupling during high power operations