Field Aligned 4-strap ICRF Antenna Design


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\textsuperscript{2}
Underlying cause of impurity generation is believed to be the presence of unwanted $E_\parallel$.

Rotate antenna structure $10^\circ$ to be perpendicular to the total B-field.

- Along a field line $E_\parallel$ will cancel due to symmetry breaking, which is expected to reduce impurities.

Similar vacuum spectrum as previous J.

To reduce impurities, present non-floating antennas are operated in dipole $[0,\pi]$, rather than monopole or current driven sheath field, estimated sheath field is reduced $\sim 3-10$.

Along a field line $E_\parallel$ will cancel due to symmetry breaking prevents $E_\parallel$ from vanishing.

For $\theta \sim 0$, sheath field is negligible – a surprising prediction. (see Garrett et al., UP9.0003)
One of the primary goals of the CTF physics program is to:

- Develop reliable heating and current actuator that can be utilized to optimize plasma performance with minimum impact on plasma.

ICRF provides bulk auxiliary heating Mod thus have access to a wide absorption scenarios.

- Fundamental H (strong SPA) and (weak SPA) are primary heating scenario.
- Mode conversion and second harmonic cyclotron scenarios are investigated,
- and Fast Wave electron heating (very also available.

F share characteristics are expected to those in ITER:
- Power density exceeds anticipated ITER power density.
- Single pass absorption (SPA).
- PFCs (Mo) that has similar sputtering characteristics as tungsten.
<table>
<thead>
<tr>
<th>Frequency</th>
<th>D &amp; E Antennas</th>
<th>J Field aligned antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 MHz</td>
<td>40-80 MHz</td>
<td></td>
</tr>
<tr>
<td>2 x 2 MW</td>
<td>4 MW</td>
<td></td>
</tr>
<tr>
<td>2 x 2 Strap</td>
<td>4 Strap</td>
<td></td>
</tr>
</tbody>
</table>
flux during ICRF operation can limit plasma performance, particularly high performance.

Apple performance with ICRF and metallic PFCs is efficient.

Apple impurity source is dependent on impurity element.

based impurities with ICRF is generally base, the underlying physics is yet unclear and phenomenology often differs.

all data indicates the primary RF impurity source is from the antenna.

ocal source at antenna is present but not dominant.

placing Mo tiles with B tiles did not improve plasma performance.

X-U data indicates RF source is the RF limiters.

results from early '90's indicated the Faraday screen primary source.

ickel from the Faraday screen increased in the core plasma during antenna operation.

eryllium coating reduced nickel influx.
Performance with $P_{rad}/P_{in}\sim 0.5$ have highest

- Typically controlled by boronization in C-Mod.

- Strategies have been pursued to control

  - Low Z coatings or plasma facing materials.
  - High performance discharges with low impurity

- L-mode has L-mode like particle and impurity
  confinement with improved energy confinement.
  - DA H-mode has modest impurity confinement.
  - LMode H-mode utilize the ELMs to control impurity
  accumulation.
  - Utilize so-called dipole phasing.
  - Utilize Faraday screen to shield direct contact with
  plasma.
  - Utilize low Z materials on the antenna.

- High performance discharges with low impurity

- Utilize so-called dipole phasing.
  - Employ Faraday screen to shield direct contact with
  plasma.
  - Utilize low Z materials on the antenna.

- High performance discharges with low impurity
Precise understanding of the physics or process determines film lifetime, low Z films, often in-situ, have a limited lifetime. Element degradation apparent after 50 MJ total RF energy. In plasma sprayed boron tiles improve the lifetime of normalization. Ion seeding also increases the boron coating lifetime. Erosion appear linked to the active antenna. Sheaths are measured on field lines connected with the antenna. Consistent with RF enhanced sheaths. It suggests deposited Mo, W and steel on the film originating from melting. If melting occurs, surface will be contaminated. Limited value in a steady state device unless a way to continuously renew the coating.
Element modes with low particle confinement relax the constraint that does not require boronization for high performance. Performance modes that tolerate impurity seeding have less stringent impurity sources.

Using restricts ICRF antenna operation to relatively high \( k_{||} \) and junctions.

Experiments show that dipole \((0, \pi, 0, \pi)\) phasing is more effective heating than \((0, 0)\) phasing. Monopole phasing has higher loading due to smaller evanescent region. Analysis has shown dipole has lower sheath voltages by factors of 2-3 than monopole. Direct drive requires traveling wave launch or \((0, \pi/2, \pi, 3/2\pi)\).

The Faraday screen with the total magnetic field has had mixed results. A final conclusion was derived from experiments using monopole phasing. Use of dipole phasing, number of experiments have shown little dependence on Faraday alignment. Observations, however, suggest alignment should reduce sheath fields.
Experiments have found no specific RF source location:
- Coated with 75-100 \( \mu \text{m} \) of Boron.
- Boron coating was not eroded.

Discrete impurity events or injections however are observed:
- Impurity injection events often limit plasma performance.
- Impurity injections are reduced/eliminated with impurity scavengers.

Sheath potential measurements are more complex than:
- Plasma potentials differ differently with conditioning.
- Observe that plasma potentials are about twice as much for H-mode than L-mode.
Dense velocity profiles are significantly modified in SOL and edge of order 1 cm.

Wave begins propagating between 91-91.5 cm and near field are limited to 90 and 91 cm.

Wave perpendicular wavelength is of order 10-15 cm.

Observed is dependent on RF power, edge q, magnetic configuration, and magnetic field.
based upon the previous J a with the antenna rotated 10° atl the entire antenna structure is ndercul to total magnetic field.
a to
ably operate at 2 MW (reduced from 3 W) into high performance plasmas; e 50-80 MHz range, and 50 kV ge handling;
e pulse length up to 5 seconds with 30 utes between pulses;
e thermal loads at plasma limiter of MW/m² with a 3 mm scrape-off th;
stand a disruption load of 1 T/msec at
ll is to be fed through a single
<table>
<thead>
<tr>
<th>Dimensions in cm</th>
<th>D/E</th>
<th>J</th>
<th>Field Aligned</th>
</tr>
</thead>
<tbody>
<tr>
<td>major radius</td>
<td>91.3</td>
<td>91.2</td>
<td>91.3</td>
</tr>
<tr>
<td>rod</td>
<td>91.7</td>
<td>91.8</td>
<td>91.7</td>
</tr>
<tr>
<td>between rod</td>
<td>0.8</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>major radius</td>
<td>93.5</td>
<td>93.6</td>
<td>93.4</td>
</tr>
<tr>
<td>center to center</td>
<td>25.75</td>
<td>18.6</td>
<td>18.6</td>
</tr>
<tr>
<td>pitch</td>
<td>10</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>depth</td>
<td>44.25</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>End fed center</td>
<td>Folded</td>
<td>Folded</td>
<td>Folded</td>
</tr>
</tbody>
</table>
The antenna has a smaller surface area compared to the previous J antennas aligned to toroidal magnetic field. The toroidal spacing is the same as for the previous J antenna, but the toroidal mode phase \(\phi\) is significantly lower.

The requirement to operate down to 40 MHz for lower frequencies is expected to be met.

The total coupled power is 2 MW/m^2, the total power density is \(\sim 10^{-11} \text{ MW/m}^2\).

Current phasing between straps is the same as for the previous J antenna, toroidal spacing is increased, leading to a minor increase in toroidal mode number compared to the previous J antenna. The phase \((0, \pi, 0, \pi)\) is \(\phi \sim 13.2\) compared to...
we have observed two types of voltage arcing where the RF electric field is parallel to the magnetic field (E||B).

The experimental limit E||B~10 kV/cm.
The voltage limit due to high neutral pressure, led neutral pressure limit.

φ and E antennas have higher neutral pressure limit compared to previous J antenna.

The toroidal geometry and single port have regions E||B.

Estimated that E||B< 10 kV/cm for 2 MW into de discharges.

The neutral pressure limit, the field aligned

Port vacuum 30 Ω transmission lines
Utilizes 5.5” feedthru versus 4.5” feedthru.
Screen is aligned to B-field and is 50% transparent.

Faraday rods are 1 cm TZM rods that are TiCN coated.

- One end is grounded and the other end is resistively connected to control currents during disruptions.

Resistive connection was designed to be $\sim 2 \, \Omega$ using a washer.

- Surface resistance could increase the resistance to $10 \, \Omega$.
- Insulator is shielded from plasma by washer and buried in Boron carbide and Zirconia bushing.
The integrated $E_\parallel$ along a field line
the antenna needs to have similar
coupled along the entire length of the
electric field passing in front of the antenna.

Symmetry dictates utilizing balanced, double
current strap.

The structure mounted to cylindrical
aluminum.

Lower loop on strap 2 and upper loop on
3 are most restrictive and set loop areas
for straps.

Protection limiters and Faraday
elements also made similar across
antenna.

Symmetry needs to extend to image currents
and.

Currents contribute to the net applied
Symmetry is critical, the antenna is fitted with the model to verify the antenna is as symmetrical as designed.

CMM arm (coordinate measurement machine) to compare the antenna with the model.

If the vessel wall deformation was large.

IJ wall differs from JK wall.

Each back plate has slight different radius.

Use picture frame shims for fine positional adjustment.

The mating surface between back and plates was tapered resulting in a potato shape.

Re-machined surface to eliminate tapers.

Antenna position in-vessel and the surfaces to be well within tolerance.
A strap has two sets of current probes.
These probes are located at the top and bottom of the strap.
They are used for monitoring of antenna impedance.

With the TZM protection tiles, the TZM tiles are instrumented with thermocouples.
Their design includes thermocouples as the thermocouples used in antenna limiters.
The thermocouple response time is insufficient to measure the surface temperature or heat flow and after shot temperatures with mass and surface area to calculate energy flux for each instrumented tile.

A probe on H side of rotated...
Begin antenna operation at 78 MHz in dipole configuration. We will begin by operating into vacuum to investigate voltage limits in vacuum. Plasma operation will be to investigate current and power handling. At the neutral pressure limit.

If the fraction is reasonable, we should investigate plasma response and compare D and E antennas. Investigate plasma response as function of antenna phase, plasma current and density.

The range of antenna phase is dipole \((0, \pi, 0, \pi)\), broad \((0, \pi, \pi, 0)\), super dipole \((0, 0, \pi, \pi)\), quint drive \((0, \pm\pi/2, \pm\pi, \pm3\pi/2)\), pi-thirds \((0, \pm\pi, \pm\pi, \pm\pi)\), and monopole \((0,0,0,0)\).

Vacuum operation expected after APS and IMC.
predict antenna performance is lacking. An extensive effort and best intentions.
Movement is typically made iteratively.

where $E||B$ could set high voltage limit.

na bridge section.

through to strip line transition and current strap d.

fed center grounded straps would remove resion and increase effective current strap length.

enter grounded strap would symmetric o magnetic field.

resses additional holes in vacuum chamber.

ground may be too large and insufficiently from the plasma.

do contact resistance, the resistance is $\sim 10 \ \Omega$ re to intended $2.5 \ \Omega$.

and arc damage at the J antenna resistive ground w we shielded the connection.
A specific antenna has been designed and installed in a structure. It is rotated 10º to be perpendicular to the B field.

A field line $E ||$ will cancel due to symmetry and is expected to reduce impurities.

The designed antenna has a smaller surface area and fewer current straps than D/E antennas.

Current density is higher for given coupled power.

The antenna has regions where $E || B$ will be greater than 10 mV/m at some power level (>2MW).

The antenna has a suite of diagnostics.

Components include current and voltage probes on each strap, thermocouples in the limiter tiles, and a reflectometer at the antenna center.

Operation expected after APS and first plasma.