ICRF antenna design studies for Alcator C-mod
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Introduction
Two major challenges for ICRF utilization are reducing impurity generation and increasing reliability at high voltages. In Alcator C-MOD, we are designing a new 4-strap antenna where we seek to lower S-parallel and improve voltage handling. Simulations were conducted to analyze the effect of antenna orientation on the parallel electric field, which is thought to influence impurity production. Previous experiments suggest that improved voltage handling may be obtained through the use of refractory metals compared with copper. A test stand has been designed and built to characterize ICRF relevant voltage breakdown.

ICRF Breakdown
The ICRF Breakdown Experiment is a tapered double ridge waveguide which will be used to study ICRF relevant voltage breakdown.

- Compact design
- High E-fields between ridges
- Source sees matched load until breakdown event (no tuning)
- Provides robust method to benchmark Cu [present ICRF strap material] against alternative refractory materials
- Variable field and neutral pressure
- Voltage/current probe, optical diagnostics to analyse breakdown – quantitively dark current, field emission data

Motivation
Evidence of arcing on Alcator C-MOD ICRF antennas. Alternate materials have the potential to increase voltage handling of ICRF antennas and striplines.

- Refractory metals: high tensile strength, high melting point materials may breakdown at higher surface fields [3, 4].
- B-field limits: electric fields at-B-orientation (ICRF operating limit) 1.5MV/m for E9 & 3.5MV/m for E0 on Alcator C-MOD [1].

FEM simulation
Finite element simulations were conducted for simplified slab and cylindrical geometries for a two strap antenna. The Alcator C-MOD ILE antenna was used as a model. Simulations were carried out using both the cold-plasma dielectric tensor and isotropic dielectric chosen to mimic observed antenna loading.

- Solid OIE Copper ridge within lower waveguide. Upper ridge will be positioned just above this ridge with the waveguide cover. The assembly will be placed into a megnetic vacuum chamber. The two RF coaxial center conductors are shown. Also visible are the circular pumping/drastic ports and one of the electrodes.

- Simulated and measured transmission and reflection coefficients are in good agreement.
- Excellent match at design freq. (70 MHz).
- Breakdown measurements will follow shortly.

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Motivation
ICRF sheaths are thought to contribute to impurity production in tokamak plasmas [5, 6]. By decreasing the parallel E-field within and around the antenna box, impurity production is anticipated to decrease.

Assumptions and simplifications
The simulations performed here are a simplified model. These simulations can provide a qualitative description of the relevant electric fields, as long as the assumptions are considered:

- m3 reduced below 10°-2 in regions where E3 is calculated (vacuum fields)
- S3 = 0° can be assumed
- Slab geometry for rotational simplicity (antenna geometry must be modified for cylindrical of toroidal rotation)
- No faraday screen
- Radiative boundary condition is used

Magnetron inductively coupled plasma. Cathodes are 1-2 mm in diameter.

Model

- 2.5M degrees of freedom
- 1.5M elements
- Run on quad core 32Ghz CPU with 8Gig RAM
- >10 elements / wavelength
- S11 = 45dB (10MW/pulse)
- F_p = 45MV (10MW/pulse)

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Double Ridge Waveguide Frequency Response

Double Ridge Waveguide E-Field simulation

Simulations demonstrate a high, peaked field in the center of the double ridged waveguide. Extraction of WSS (peak) produces 7.5MV/m at electrode location. E-field scales as sqrt(Pin).

- Electron channel to test various refractory materials

Neodymium magnets below Voltage to inspire up to 1T field across gap

BeCu fingers for optimum electrical contact between electrode and ridge

Distance [cm] 0 0.3 0.6 0.9 1.2 1.5-0.35
-0.25
-0.15
-0.05
0.05
0.15
0.25
0.35
Abs (Vll) 10
, 0-0
Potential [kV] Y position [m] 

2.5cm
3.0cm

Distance along guide [cm] 60 70 80 90 100
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
Double Ridge Waveguide Frequency Response

Frequency [MHz]
Amplitude [dB]

S11 measured
S11 simulation
S21 measured
S21 simulation

- Magnitude of integrated parallel E-field plotted on surfaces 2.5 cm and 3.5 cm in front of antenna straps. Both E9 and E0-0 phasing are plotted. Angle is with respect to equilibrium B-field. Solution is in region of vacuum fields (see density profile).
- Note the large reduction in Vmn for 0-phasing as the straps are aligned to equilibrium B-field. For realistic density in SOL, these values will decrease substantially as E-fields are shielded.

Parallel E-field

Integrated E_i

Plotted on the same scale, we can see the dramatic reduction in Vmn when the antenna is perpendicular to the equilibrium B-field and operated in 0-0 phasing (+0.25 cm).

Cylindrical field

Integrated E_i

Cylindrical simulations qualitatively agree with slab model. Antenna strap geometry must be modified for rotational analysis in cylindrical or toroidal coordinates.

Alcator C-mod rotated design

Design is to be based upon the existing double balanced 4-strap antenna while targeting performance 25% higher in voltage than the 2-strap antennas currently in use.

- Reduce transonic erosion and impurity production.
- Improve voltage and power handling.

Antenna general specifications
- Operate at 2 MV (down from 3 MV) and 50 kW
- Have pulse length up to 3 seconds at repetition time of 1000 s
- Have thermal loads at plasma limit of 12 MW/m² with a 5 cm scope-off length
- Withstand a disruption load of 1 T-made at 9 T
- Utilize single horizontal port, and have 50-80 MHz range.

Summary
ICRF Voltage breakdown experiment
- Initial results suggest that performance will match simulations.
- Experiments will characterize refractory materials relative to Copper.
- ICRF simulations of a simplified two strap ICRF antenna
- Results suggest that a rotated topology (perpendicular to B) will decrease E9, especially when symmetric phasing is used.
- Simulations are being done to better quantify E9 with particular emphasis on SOL effects at limiter surfaces.