High Power Antenna Design for Lower Hybrid Current Drive in MST

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Abstract

RF current drive has been proposed as a method for reducing the tearing fluctuations that are responsible for anomalous energy transport in the RFP. A system for launching lower hybrid slow waves at 800 MHz and $n_\parallel = 7.5$ is now in operation at up to 50 kW on MST. The antenna is an enclosed interdigital line using $\lambda/4$ resonators with an opening in the cavity through which the wave is coupled to the plasma. It has an untuned VSWR of $\sim 2$, and is instrumented on 5 of its 23 elements to allow measurement of damping length. The antenna design is being optimized for higher power handling. Improvements include larger vacuum feedthroughs, better impedance matching, and RF instrumentation on all resonators. The new antenna will be modeled in Microwave Studio™. The goal is a design which can handle $\sim 250$ kW and presents a VSWR of 1.4 or better without external tuning. Full instrumentation will allow more detailed power deposition measurements.
Current profile modification to improve RFP

MHD simulations of $\mathbf{J}(r)$ control in the RFP show reduced magnetic fluctuations

- Inductive current profile control (PPCD) shows increased $T_e$, $\tau_E$, decreased fluctuations, 100 keV x-rays
- RF waves (LHCD, EBW) accessible despite "overdense" plasma ($\omega_{pe}^2/\omega_{ce}^2 \gg 1$)
Lower Hybrid wave is accessible at 800 MHz for $n_\parallel \geq 5$ at 500 kA in MST

- Wave drives current by damping on electrons at 3-4$v_{th}$
- Inboard launch at $n_\parallel = 7.5$ chosen for localization near $r/a = 0.75$
Experimental Status

Second generation LHCD antenna has been operated in MST for 1 year

- Antenna has been conditioned for operation up to 50 kW
- Plasma loaded power damping length has been measured

Design of 200 kW system is underway

- Third iteration of antenna design
- Transmitter upgrade for 200 kW operation
Traveling wave design produces slow wave with $n_{||} \approx 7.5$, and $\overline{E_{||}}B$

- RF power is fed through coaxial ports impedance matched to end elements
- Wave launch direction is reversed by interchanging driven and terminated ports
Good impedance match with plasma up to 50 kW input power

- Large fraction of power is coupled to plasma ($|T|>60\%$ in vacuum)
Antenna instrumented with RF power sampling loops behind center 5 radiating elements

- Loading is consistent with analytical estimates, depends weakly on $P_{RF}, n_e$
- Next antenna will have probes on all elements to better constrain the fit
High Power Design Issues

Larger vacuum feedthroughs for 200 kW operation

- 2 cm diameter coaxial feedthrough tested to 50 kW
- 4 cm version in development for next antenna
- Necessary portholes added to MST during recent upgrade

Reduce standing waves along antenna

- Suspected of contributing to multipactor breakdown
- Optimize phase velocity on slow wave structure
- Improve impedance match at feeds to reduce reflections
Vacuum Feedthrough Design

Vacuum brazed coaxial copper-alumina disk seal

- Designed and fabricated at UW
- Withstands >100 MW/m²
Feedthrough has been redesigned for higher power

- Reflection coefficient $<-40\text{dB}$ from DC to 950 MHz
- Should handle 200 kW at same power density as existing feedthroughs
Electromagnetic Simulation

First antenna 2D analytic $\Rightarrow$ SPICE

- Assumes TEM modes on resonant elements
- Neglects transmission line end effects

Second antenna 3D electrostatic FEM $\Rightarrow$ SPICE

- Assumes TEM modes
- Includes lumped end capacitances

Next antenna 3D electromagnetic using CST MicroWave Studio™
Slow wave structure optimized for 800 MHz operation

- Periodic boundary simulation of interdigital line
- Eigenmodes calculated for $0$ thru $\pi$ phasing between elements
Interdigital line bandwidth verified to be $\sim 5\%$

Present antenna is slightly detuned

- Optimized structure differs by only 1%
- At 5% bandwidth this shifts $n_\parallel$ by 20% ($7.8 \rightarrow 6.2$)
Simple model to test interaction of new feeds and impedance matching section

- No curvature $\rightarrow$ simpler to mesh
- No aperture $\rightarrow$ smaller simulation domain
- Short travelling wave section $\rightarrow$ short simulation time
Optimization of antenna structure is proceeding, with several goals:

- Minimize reflections at feeds
- Minimize ripple in passband of antenna
- Present $50\Omega$ impedance in coaxial sections
Klystron beam power supply is being upgraded for 200 kW operation

- Initial HV pulse length 30 ms, can be increased to 50 ms
- PFN can drive second tube when available for 400 kW total
### Future Work Plan

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- Antenna installed in MST by mid 2004
- Transmitter upgrade proceeding
- Instrumentation upgrade after antenna design is complete
Summary

50 kW LH travelling wave antenna in operation on MST

Design of a 200 kW antenna is underway

Electromagnetic design using CST MicroWave Studio

High power system ready mid 2004
Reprints