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RF Systems for a Proposed Next Step Option (FIRE)*

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Abstract. FIRE (Fusion Ignition Research Experiment) is a high-field, burning-plasma tokamak that is being studied as a possible option for future fusion research. Preliminary parameters for this machine are $R_0 \approx 2$ m, $a \approx 0.5$ m, $B_0 \approx 10$ T, and $I_p \approx 6$ MA. Magnetic field coils are to be made of copper and pre-cooled with LN_2 before each shot. The flat-top pulse length desired is $\geq$ 10s. Ion cyclotron and lower hybrid rf systems will be used for heating and current drive. Present specifications call for 30 MW of ion cyclotron heating power, with 25 MW of lower hybrid power as an upgrade option.

1. INTRODUCTION

The FIRE tokamak (1) is designed as a Cu-coil, high-magnetic-field tokamak that can achieve a burning DT plasma. The ion species mix is nominally 50:50 D:T, with some possible minority H or He^3.

A design that can meet the ion cyclotron (IC) requirements has been developed that uses four two-strap antennas mounted in main horizontal ports. Heating frequencies considered are 150 MHz (H minority or second harmonic D) and 100 MHz (He^3 minority or second harmonic T).

A *very* preliminary conceptual design of a lower hybrid system has been carried out. A multi-junction launcher operating at 8 GHz has been designed that fits in a main horizontal port and extends vertically about 60 cm. Launchers installed in two ports will deliver the required 25 MW to the plasma.

2. ION CYCLOTRON SYSTEM

We have concentrated on the antenna configuration and the coupling of the antenna to the plasma, as these are the most critical parameters for initial system design. Power sources in this frequency range, along with tuning and matching

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equipment and concepts, will follow reasonably conventional (although state-of-the-art) designs.

Figure 1 shows a view from the plasma of a proposed antenna configuration that can operate at the frequencies chosen above. The antenna fits through a main port, allowing for easy installation and removal. The antenna consists of two current straps, each strap 15 cm wide and 119 cm tall. Each strap is grounded to the case at both ends. The straps can be grounded at the center point also, if desired, for increased mechanical strength.

Each strap is driven out of phase by two coax feeds. The resulting voltage and current profiles along a strap are shown in Fig. 2. We use π phasing between adjacent straps, since there is no current-drive requirement on the IC system.

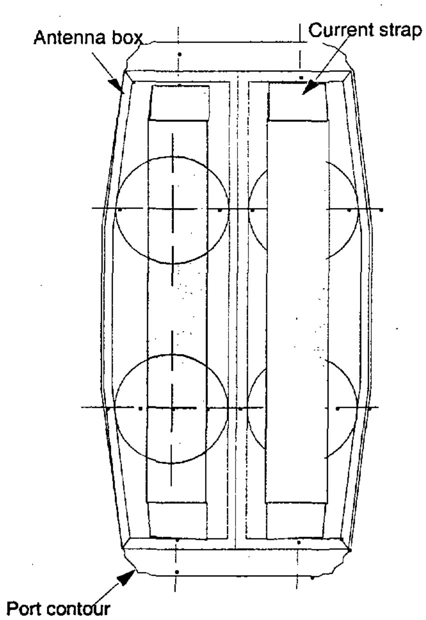

FIGURE 1. Front view of two-strap ion cyclotron antenna.

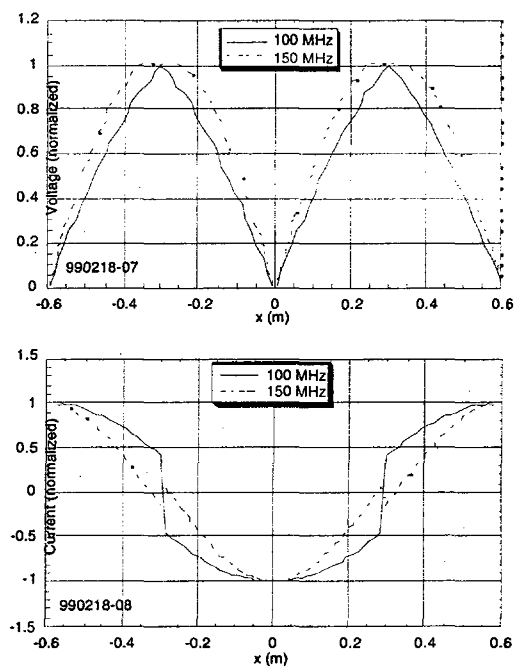

FIGURE 2. Voltage magnitude and current along one current strap, for two frequencies.

The voltage and current profiles were calculated using a lossy-transmission-line model of the antenna with $Z_{strap} = 50\ \Omega$ and $\beta_{strap} = 0.55$. The electrical wavelength of the straps is near one wavelength in the 100 – 150 MHz frequency range, making the double-grounded configuration feasible. The advantage of this configuration is the mechanical strength of the straps. For the cases shown in the figure, the current at strap ground was set equal to 1.0 kA.

The antenna is covered by a Faraday shield (not shown), consisting of a number of metal tubes. Active cooling will be required for the predicted heat loads of ~100 W/cm^2 from radiated power plus rf losses and neutron heating.

The RANT3D code (2) was used to compute the plasma loading resistance R' for the antenna geometry shown in Fig. 1. In this calculation, we assumed that the front of the Faraday shield was flush with the first wall. The definition and values of antenna dimensions used in the modeling are given in Table I.

TABLE 1. Dimensions of the FIRE antenna used in loading calculations.

Dimension	Value (mm)
Cavity depth	300 (not critical)
Distance from Faraday shield front to strap front	20
Thickness of straps	10
Strap width	150
Cavity width	260
Distance between current strap centerlines	310

The density profile was taken as a parabolic-to-a-power, with power α_N values of 0.5 and 0.2 being used. The density at the separatrix was assumed to be 20% of the central density, and the e-folding distance of the density in the plasma scrapeoff region outside the separatrix was taken to be 1 cm.

Figure 3 shows the results of the calculations with $<n> = 4.5 \times 10^{20}$ m^{-3}. The left figure plots the loading resistance per unit length (R') vs. gap. The plot on the right shows the value of voltage in the system required to deliver 30 MW to the plasma from antennas mounted in four main ports. For both figures, the x-axis (the "gap") is defined as the distance from the first wall to the plasma separatrix at the outer midplane.

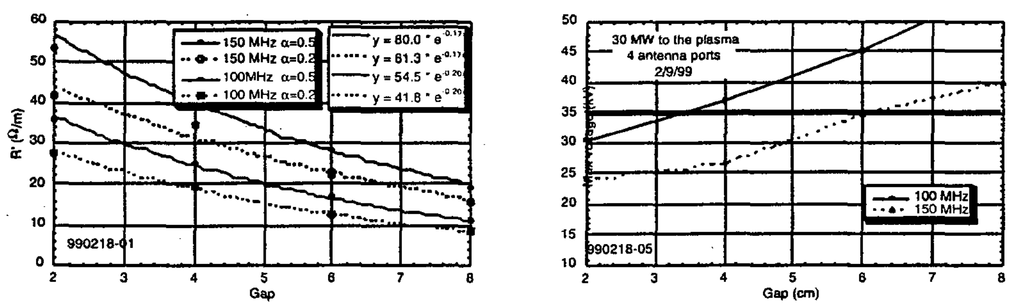

FIGURE 3. R' vs. gap for 100 and 150 MHz (left), and maximum voltage required to deliver 30 MW to the plasma vs. gap (right). Inter-strap phasing is π.

The nominal gap value is 3.2 cm, based on the most recent FIRE plasma equilibrium calculations. For these conditions, V_{max} = 35 kV at 100 MHz, and 26 kV at 150 MHz.

LOWER HYBRID SYSTEM

The addition of a lower hybrid system for heating and off-axis current drive is a possible upgrade option. A study has been done to determine the characteristics of a 25-MW LH system for FIRE.

In order to drive current efficiently, the operating frequency must be at least twice the lower hybrid frequency. For n ≈ 5 x 10^{20} m^{-3} and B = 10 T, f_{LH} ≈ 2.7 GHz. We chose an operating frequency of 8 GHz based on this requirement. The launcher is made up of a number of waveguides 3.6 cm high by 0.3 cm wide (based on single-mode operation and peaking the launched spectrum at $n_{\parallel} \approx 2.5$). Figure 4 shows a plot of power flux capabilities vs f^2b (3) for other LH systems; based on this graph, we chose an operating power flux of ≈ 60 MW/m^2. To deliver 25 MW then requires about 0.4 m^2 of radiating area, or approximately 3,800 waveguide elements. Figure 5 shows a sketch of a possible array geometry in a FIRE port. Two such ports will deliver the required power.

For the LH launcher to operate efficiently, the LH launcher contour must conform closely to the plasma contour for good coupling. The larger the poloidal extent of the coupler, the greater the constraint on the geometry of the plasma outermost flux surface. The 61-cm height shown should allow for some changes in plasma geometry (e.g., κ, δ) , without degrading coupling too much. More detailed calculations of loading vs. plasma shape will be required.

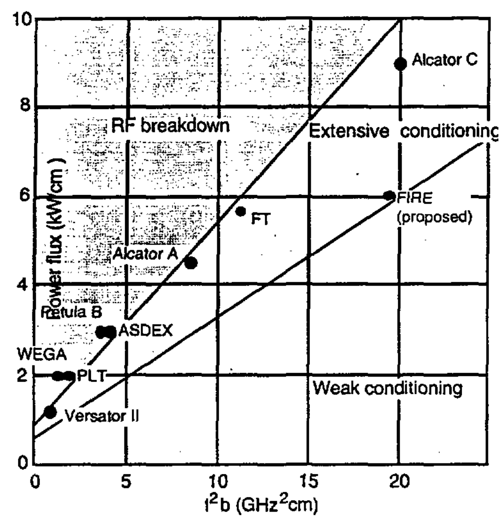

FIGURE 4. RF power flux vs. f^2b in LH systems (b = waveguide width).

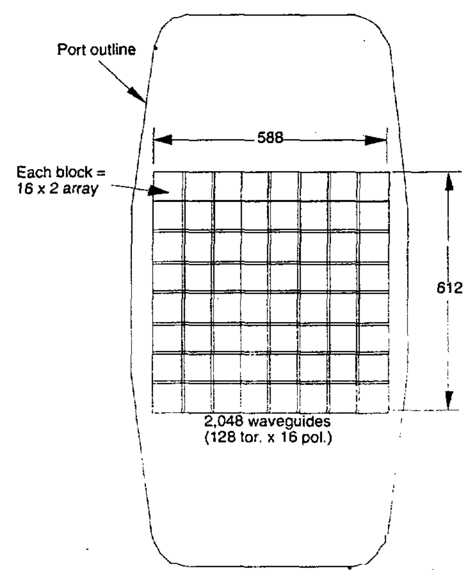

FIGURE 5. LH launcher in port.

REFERENCES

1 Meade, D. M. and Wooley, R.D.,"A Compact Advanced Burning Plasma Experiment," in *Proc. of 20th Symp. on Fusion Tech.*, 1998, pp. 1713-16.

2 Carter, M. D. et al., *Nucl. Fusion* **36**, 209-223, (1996).

3 S. Bernabei, private communication.