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ICRF ANTENNA MODIFICATIONS AND ADDITIONS FOR TFTR--RELEVANCE TO BPX/ITER PROJECTIONS*

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ABSTRACT

The TFTR Bay L and M antennas have been modified to improve their power handling capability. In particular, the Bay L antenna, which exhibited a lower than expected loading resistance,[1] now has a configuration similar to that of Bay M--slotted walls and septum--and together with Bay M is expected to support 7 MW operations. The in situ loading enhancement achieved for the Modified Bay L design will serve to quantify models for the coupling effects of slots. Also, comparisons with Bay M loading performance will elucidate wave spectrum and antenna location (relative to in-vessel structures) effects. Two new antennas, with single/double row shields slanted at 6° (along B) are to be added in the near future to augment the power capability to ~12.5 MW. The relevance of the four antenna array features to quantifying BPX/ITER antenna characteristic projections for heating and current drive is discussed.

ANTENNA MODIFICATIONS ON TFTR

The Bay M and L antennas on TFTR[1] have been modified to improve their power handling capability. Notably, the side tiles for both antennas have been moved toward the plasma to provide a plasma scrape off distance of ~3 mm to the Faraday shield and Bay L has been converted from its previous solid wall/septum configuration to the slotted wall/septum configuration of Bay M as shown in Fig. 1. The increased tile scrape off distance is expected to greatly reduce plasma-shield interaction as observed for in-phase current strap operation of the Bay M antenna[1] and the modification of Bay L is expected to enhance its unexpectedly low loading level[1] sufficiently to permit its operating power density to be extended to the ~10 MW/m^2 range as achieved with the Bay M antenna.[2]

The significant modifications to the Bay L antenna which will affect loading include (i) slotted walls/septum, (ii) a V-shaped Faraday shield to match the field contour, and (iii) a current strap-shield separation of 1 cm (from 1.5 cm). These characteristics are essentially those of the Bay M antenna. Primary differences which remain relative to the Bay M antenna are that the antenna current straps are closer together (23 cm vs 30.5 cm) and that the modified Bay L antenna is still immediately adjacent to an outboard RF limiter whereas the Bay M antenna is located midway between the outboard RF limiters[1] (separated by ~3 m). Thus a comparison of the modified Bay L antenna loading characteristics with those of the previous Bay L antenna will highlight the influence of the modifications directly, especially that of the slots, whereas a direct comparison with the Bay M antenna characteristics will highlight the effects of spectral differences caused by current strap separation and the effects of structures (limiters).

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Models for predicting the effect of slots on loading are being developed[3] and will be checked against the planned measurements. In order to have a preliminary estimate of the power enhancement which could result, we note that if (i) the antenna-limiter separation proves to be unimportant, (ii) the small increase in tile shadowing of the shield has a minor effect, and (iii) the density gradient is relatively steep in the plasma edge, then the loading can be scaled from the Bay M values[4] to the extent that the slots have the same effect on the wave spectrum for the two antennas. In this case, the relative loading would scale as exp (-2 $\times \Delta k_{||} \times X$) as shown in Fig. 2 for X = 8 cm. Here X has been taken as the position to the last closed magnetic surface of the plasma boundary and hence the estimate of an improvement of a factor of ~3 in loading (at 8 cm) is perhaps optimistic.[5] However, only a factor of ~1.5 is required to achieve the desired operating power level of ≳3 MW. (The Bay M loading deviation from the scaled Bay M curve for X > 20 cm is thought to be due to changes in the density profiles associated with the plasma displacements required to obtain those data points.)

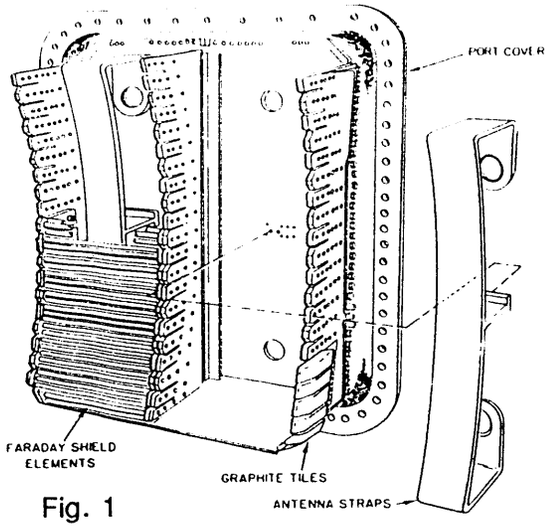

Fig. 1

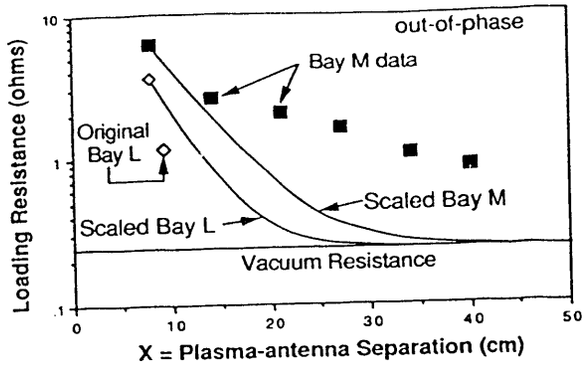

Fig. 2 Scaling of loading from 8 cm Bay M data.

UPGRADE OF THE TFTR ICRF SYSTEM TO 12.5 MW CAPABILITY

Two new antennas are being prepared for installation on TFTR at the beginning of 1992. These antennas will be placed at Bays K and N as shown in Fig. 3 and are intended to bring the total system power handling capability to ~12.5 MW. They both have the slotted configuration (Fig. 1) with the Bay L dimensions but the Faraday shield elements are aligned with the magnetic field (6°) so that a direct evaluation of the effect of shield alignment on impurity generation for the same discharge will be provided by the compliment of antennas. Furthermore, the Bay K antenna has a single row

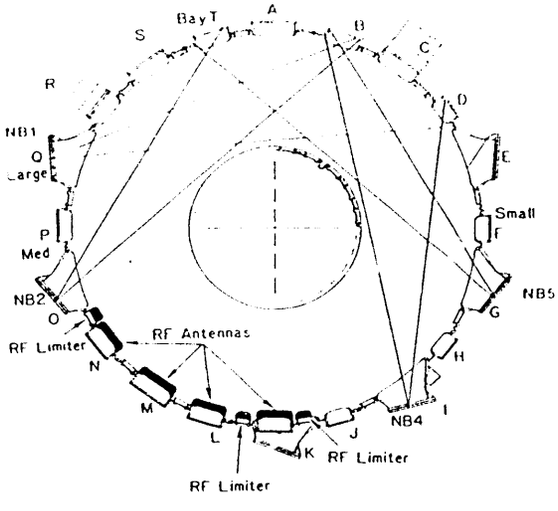

Fig. 3 ICRF 4-antenna upgrade system (~12.5 MW).

Faraday screen which is "open" relative to the others to permit possible enhancement of loading and exploration of single row characteristics for extrapolation to future antenna designs.

The actual power which will be provided by the upgrade system will be established by the upcoming modified Bay L performance tests. It is expected that the power capability will be in the range of ~12.5 MW which will support the major research objectives of (1) maximizing reactivity in the supershot regime at full neutral beam power (~35 MW) and at relatively high plasma current (~2.5 MA), and of (2) investigating energetic ion stability effects for α relevant parameters.[6] The first objective is to be met by core heating and, if possible, sawtooth stabilization. The second objective is being addressed in all regimes of operation on TFTR in preparation for evaluating actual α effects during the planned D-T phase of operations on TFTR.

It is especially interesting that comparison of the sawtooth stabilization conditions observed on TFTR for minority ICRF heating to $\hat{\gamma}_I$ predictions for the ideal kink theory[6] suggest that operation at 12.5 MW could lead to the fishbone instability regime. Figure 4 indicates that the hot ion density can be tripled over that presently used for sawtooth stabilization with P_{RF} ~ 4 MW while keeping the ion tail temperature approximately constant. Thus the effect this fishbone instability has on energetic ion and hence α confinement for relevant ion tail energies may be observable.

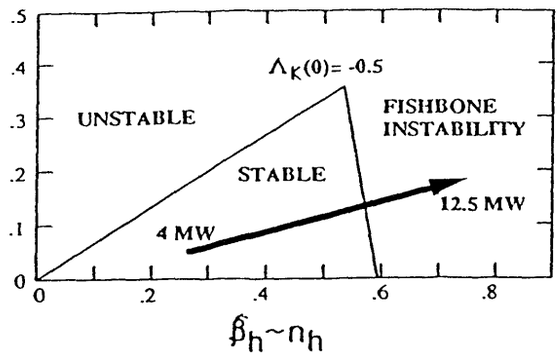

Fig. 4 Energetic ion ideal kink stabilization boundary (see Ref. 6). Fishbone region may be accessible ($3 \times P_{RF}$, $3 \times n_h$, T_h ~ constant).

RELEVANCE OF TFTR ANTENNA PERFORMANCE CHARACTERISTICS TO BPX AND ITER

Energetic ion and α stability effects are important issues for BPX and ITER with regard to optimizing D-T operation. Measurements of these effects on TFTR and JET in the D-D and D-T regimes will provide a basis for extrapolation to these more reactor relevant regimes.[6] It is especially important to capitalize on sawtooth stabilization during the buildup phase of BPX with ICRF heating and for α instabilities to be avoided, if deleterious, in both BPX and ITER.

The TFTR antenna-limiter-plasma geometry is well suited for extending the heating and coupling results to BPX and ITER. Reactor like core plasma conditions are achievable with both high power neutral beam injection (T_e, T_i > 10 keV, 25, keV; $\bar{n}_e \sim 8 \times 10^{13}\ cm^{-3}$) and pellet injection ($T_e$, T_i ~ 10 keV; $\bar{n}_e > 10^{14}\ cm^{-3}$), and edge plasma conditions comparable to those provided by the planned divertor geometries can be simulated by selecting the plasma and antenna positions. Note especially that the Bay K antenna is located between two RF limiters (Fig. 3) so that a relatively short (~3 mm) scrape off is predicted. The relative performance of the modified Bay L and M antennas and of the new Bay K and N antennas will serve to benchmark codes appropriate for extrapolating coupling characteristics to "slotted" BPX antenna designs.[7] Furthermore, diagnosis of the scrape off density with extraordinary

reflectometry is planned (ORNL collaboration) to permit the coupling analysis to include quantitative density profiles. For this purpose, access for reflectometry horns is being provided through the Bay K antenna at the center of the Faraday shield.

The antenna array on TFTR is also suitable for the study of possible transit time magnetic pumping (TTMP) effects on heating, current drive, and stability. The slotted design (Fig. 1) has a relatively high mutual couping between current straps but this tends to be offset by its relatively high coupling resistance. For a loading resistance of $R_p = 350\ \Omega$, which is typical of that achieved with the Bay M antenna on TFTR, a centerfed, two-loop Bay M prototype test antenna can be excited at 90° as indicated in Fig. 5. Note that the reflected power is down by 16 db and the currents are 90° (270°) out-of-phase. The squared current signals ($I^2 \propto V^2$) are unequal by ~2 db for this case of equal loop powers but can be made equal by reducing the power to one loop by ~2 db. For equal currents, powers will approach equality as the loading is increased further or as the mutual coupling is decreased without reducing the loading which can be accomplished with circuitry external to the launcher.[8]

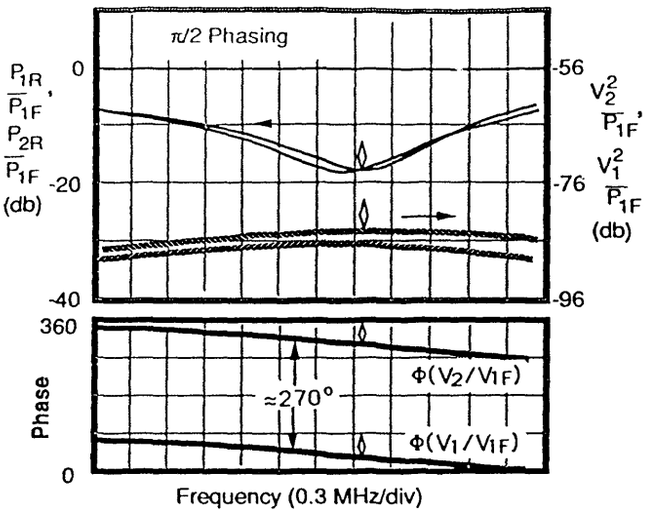

Fig. 5 90° phase characteristics on Bay M mockup with R_p = 370 Ω.
◊ = f_{res} = 32.1 MHz.

Figure 5 demonstrates that 90° phasing is possible for the slotted antenna design and suggests that this design could prove to be feasible for TTMP current drive on ITER. Furthermore, the port contained array could ultimately give sufficient directivity to warrant such a system for ITER.

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