Recent results from a Folded Waveguide ICRF Antenna development project

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Abstract. Preliminary high power tests have been performed on a folded waveguide (FWG) ICRF launcher with a curved coupling faceplate installed. Two alternative faceplate configurations have been built and tested at low power and will be tested at high power in the near future. The new designs include a dipole plate which provides a 0-π launch spectrum and a more transparent, flexible monopole face plate configuration. This FWG design is a 12 vane, 57 MHz design with a 0.31 m square cross section. The FWG can be installed with either fast wave or ion-Bernstein wave polarization and can also be retracted behind a vacuum isolation valve. A 1 x 4 FWG array optimized for fast wave current drive on DIII-D has been conceptualized.

INTRODUCTION

The folded waveguide is being investigated as an advanced ICRF launcher[1,2,3] because of a number of advantages over current strap antennas including: higher power density and power capability, all metal construction, internal matching, greater mechanical strength, lower electric fields near the plasma, more flexibility over launch spectrum and possibly greater plasma-antenna separation. Many of these features are particularly advantageous for reactor relevant plasma conditions. Although "record" high power operation of a FWG development unit has been demonstrated on the RF Test Facility at ORNL, many of these features have not been proven on a tokamak. Of particular interest are the plasma loading and the operational reliability. This project was originally undertaken to develop a FWG compatible with both the PBX-M and TFTR tokamaks at PPPL. However, the great flexibility offered by the small cross section makes this FWG quite compatible with a number of other tokamak experiments that are being considered for further testing of the device.

The FWG design under development, shown in figure 1, has 12-vanes and 0.31m square cross section and is configured as a quarter wavelength resonator that operates at 57 MHz. Input power is fed through a 150 mm coaxial line and vacuum feedthrough located at the rear wall of the FWG. The coaxial center conductor connects to a coupling loop of adjustable area which permits maintaining an input match. The design goal power capability of 4 MW would, if successful, permit operation at a power density of 5 kW/cm^2. Since this is an experimental device, all-bolted construction was utilized to facilitate modification or repair during development. The vacuum enclosure is designed to permit retraction of the FWG behind a gate valve for servicing, tuning, off-line conditioning and waveguide rotation without affecting the tokamak vacuum status. Motion of the FWG is accomplished with a re-entrant bellows around the feed coax.

RECENT HIGH POWER TEST RESULTS

High power tests were performed using the original curved faceplate on the RF Test Facility at ORNL. The antenna appears to condition through multipactor quite quickly through the use of RF bakeout. A power level maximum of 400 kW was achieved with ~10 ms pulses length and longer pulses at a lower power level. The power capability was primarily limited by arcing at joints around the faceplate. Inspection of joints in the area after operation revealed that gaps had formed from differential thermal expansion caused by overheating at high current regions. The heating rate and faceplate temperature clearly must be limited when using the standard faceplate, which is a rigid, high-strength stainless steel design. This faceplate is rather thick to permit curvature for matching the plasma edge shape. The gaps between the faceplate and the vane ends were eliminated by re-machining the ends of the vanes. To permit higher average power operation, a more flexible faceplate was designed with higher thermal conductivity to better disperse the heat and allow for slight flexing at high heating rate. The gap problem will be alleviated in production-type FWG antennas by brazing or welding the faceplates in place instead of attaching screws.

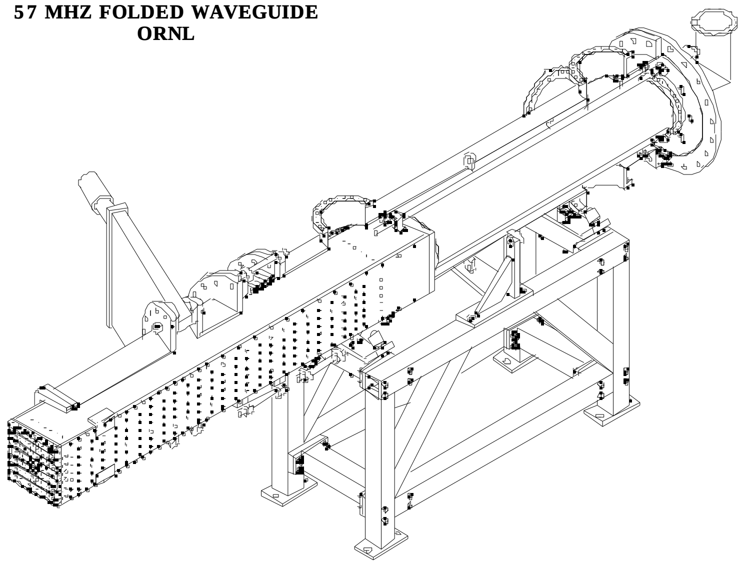

Figure 1. Exploded view of the FWG in the vacuum enclosure

ADVANCED FACE PLATE DEVELOPMENT

Two new faceplate configurations have been built and tested at low power and will be tested at high power in the near future. These include a dipole version and a more transparent monopole version. Both designs are flat and constructed from 3mm thick copper plates, which provide greater thermal conductivity to disperse heat away from hot spots. The dipole face plate is one large sheet whereas the monopole version is actually 11 small plates that attach between adjacent vanes and make no connection to the sidewalls as shown in figure 2. For tokamak operation with high disruption forces, these faceplates would be replaced with molybdenum to provide greater mechanical strength. The plates are attached by recessed flat head socket-cap screws that provide a smooth surface with minimum exposed corners that might lead to arcing. The edges of the faceplates are radiused to minimize the chance of arcing. The greater flexibility of these thin plates is expected to provide better electrical contact with the vane ends over the entire temperature range of operation.

Low power testing with the two faceplate versions installed has been performed. Measurements have included magnetic field antenna patterns and loading vs. spacing using simulated plasma absorber. The magnetic field patterns along the midplane for both versions are shown in Figure 3. This measurement was made

Figure 2a
Dipole face plate

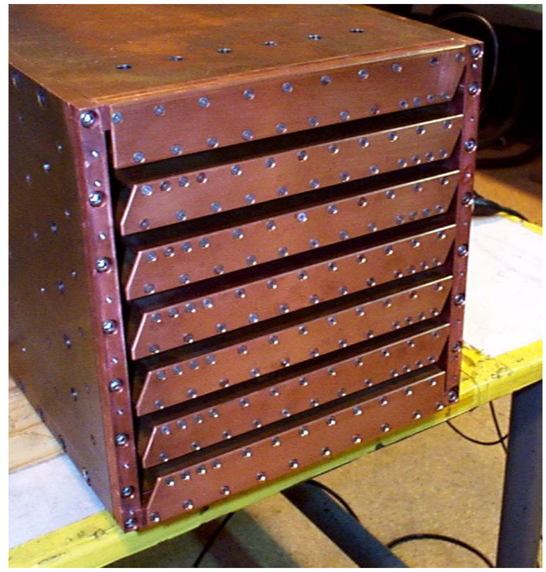

Figure 2b
Open monopole face plate

at a distance of 5 mm from flush with the faceplate so the amplitude of the edge current sidelobes is large. These sidelobes decay rapidly away from the faceplate.

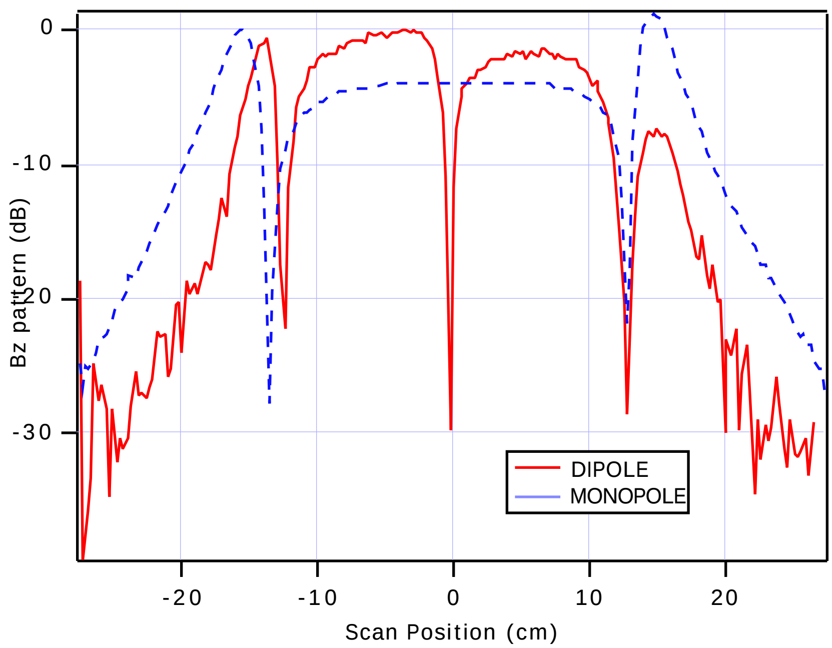

Figure 3. Comparison of monopole and dipole face plate Bz patterns

Loading measurements were performed using resistive film absorber that is varied in separation from the FWG faceplate. The ratio between the unloaded Q and the minimum Q is an indication of the maximum FWG coupling efficiency. It was found that the dipole faceplate is ~85% efficient, which is similar to measurements obtained with the original thick, curved faceplate. The open monopole faceplate has efficiency of 95% which is the highest seen of all the various face plate configurations studied to date. The variation of magnetic field and the antenna patterns were recorded vs. radial position.

FWCD ARRAY FOR DIII-D

In order to increase the usefulness of a FWG antenna for physics studies on DIII-D and other tokamaks, the possibility of building an array for generating the non-symmetrical spectrum required for current drive has been investigated. Due to its depth and width requirements, a low-frequency 1x4 FWG array is difficult to fit into most medium-sized tokamaks available today. However a 120 MHz FWG array is feasible on DIII-D as shown in figure 4. This array uses 4 identical 1-m long FWG elements with a jog near the plasma end to bring the faceplates together. Each element fed from the rear through two adjacent ports. Depending on the loading achieved, it is estimated that this array could couple 8 MW of power to the plasma. Full control over the phasing and internal matching would be possible.

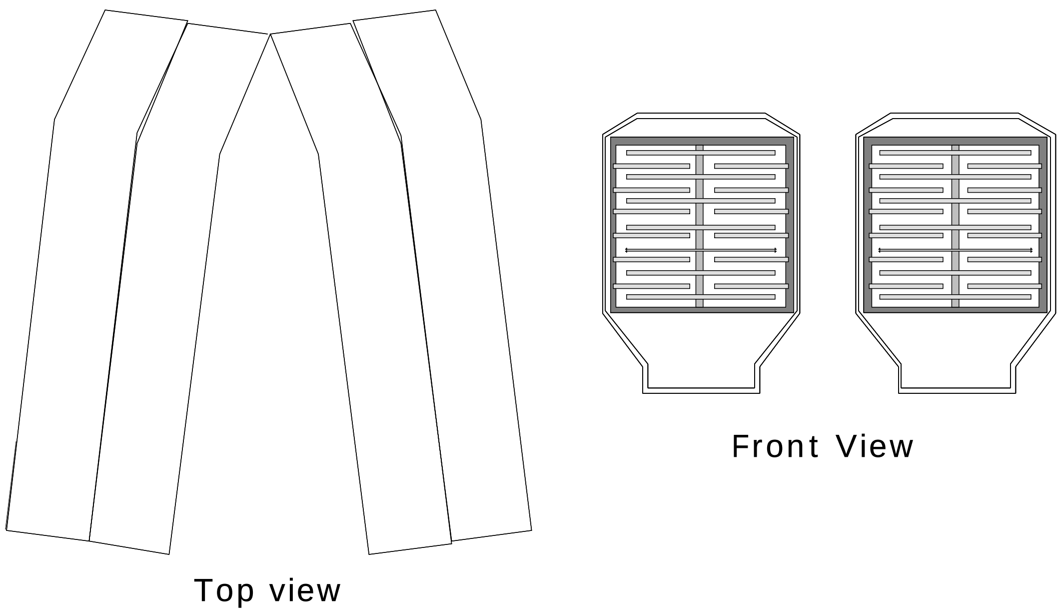

Figure 4. Proposed 1 x 4 FWG array for FWCD on DIII-D

CONCLUSION

Further high power tests on a FWG antenna were performed to gain operating experience and alleviate any operational difficulties. Two improved faceplates were tested at low power and are scheduled to be tested at high power soon. A FWCD array was also briefly investigated and appears to be feasible for DIII-D.

ACKNOWLEDGMENTS

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