Subject: D, E, and J-port Antenna Evaluation and Comparison

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1. Purpose of Experiments

The goal of this mini-proposal is to assess and evaluate the modified D, E and J-port antennas performance. A second goal is to further compare the antennas particularly the impact of different design characteristics on antenna performance.

Specifically:

- Determine the vacuum maximum voltage limit for D, E, and J-port antennas.
- Determine the operating maximum voltage limit for D, E, and J-port antennas.
- Document the loading up to 1.5 MW.
- Document the impurity production as a function of power, heating scheme (D(H) versus D(^3He)), plasma current, local plasma density
- Document heating efficiency as function of antenna phasing

2. Background

All three antennas have been modified since the last run campaign. All antennas were modified to shield BN-metal interfaces from the plasma. In the past campaign, injections from such interfaces resulted in plasma disruptions as recorded via the visible cameras. Melt damage on metal fasteners and components was found at exposed BN-metal interfaces during the post-campaign inspection. The D and E-port antennas had a triangular section of the Faraday screen removed to allow the BN tiles to improve the shielding for the BN-metal interface. In addition the Faraday screens were refurbished (melt damage was removed) and Cu-plated (brush, <0.001”). The J-port front and end tiles were modified to shield the fasteners from the plasma. The J-port antenna straps were also modified. At the strap grounding bridge, the electrode was modified to improve the
antenna maximum voltage capability. During the last campaign, the maximum voltage was limited to 25 kV at 78 MHz and 30 kV at 70 MHz. The frequency dependence suggested the voltage was limited due to the antenna strap design. The E-field between the grounding bridge and the electrode exceeded the empirical 15 kV/cm limit observed where the E-field is parallel to the B-field. To lower the E-field at this location, the gap was increased to 2 cm from 1.4 cm and the peak E-field was reduced through electrode shaping (peaking was reduced by 20%) and directed across the B-field. To assess the design improvements, the vacuum voltage characteristics and plasma maximum voltage need to be documented. The power limit and impurity production characteristics also need to be investigated. Additional information about the underlying physics of the voltage limit and BN-metal impurity production may be investigated through varying the plasma current and density, the $B_T$ field, antenna phasing, and the RF frequency.

Although the D and E-port antenna’s Faraday screens differ from J-port’s Faraday screen, impurity characteristics and heating efficiency appeared to be similar in last campaign. If this is born out in more detailed measurements, Faraday screen design and manufacturing could be significantly simplified in future antenna designs. Furthermore, the more open J-port screen and antenna box appear to have resulted in higher loading without significant decrease in antenna heating efficiency or increase in impurity generation. The documentation this would impact future antenna designs including the proposed E-port 4-strap antenna.

Prior to embarking on this proposal, the power, DC1, DC2, and stub calibration factors need to be established for the three systems. Furthermore the antennas need to be conditioned. Although antenna conditioning is subjective at best, the following performance criteria are used to define conditioned. In vacuum, a maximum antenna voltage of 40 kV for 0.5 sec will be considered vacuum conditioned. In the plasma phase, the antenna will be considered conditioned once there is little density rise associated with the RF transition on in L-mode and the maximum antenna voltage reaches $> 35$ kV and/or 1.5 MW for 0.5 sec. For J-port, the maximum antenna voltage is expected to be $\sim 36$ kV at 78 MHz and $\sim 43$ kV at 70 MHz. However, if the peak E-field along the B-field influences the voltage limit the maximum antenna voltage may exceed these estimates by 20%.

3. Approach

Describe the methodology to be employed; explain the rationale for the choice of parameters, etc. Describe the analysis techniques to be employed in interpreting the data, if applicable. If the approach is standard or otherwise self-evident, this section may be absorbed into the Experimental Plan.

3.1 Vacuum maximum voltage limit

Under good vacuum conditions ($< 10^{-6}$ Torr), determine the maximum voltage limit with care. Initially use short pulses ($< 10$ msec) to reach 40 kV. Once 40 kV is reached, lower the voltage (power) to 25 kV and increase the pulse width until a pulse width of 0.5 sec is reached. Then, increase the power until 40 kV is reached. After the
campaign, repeat this process to characterize voltage handling capability. If the maximum voltage limit appears to be $> 40 \text{kV}$, short pulses will be used to investigate the maximum limit. On D and E-port antennas, the limit may ultimately be the vacuum feedthrus ($\sim 50 \text{kV}$) and information about the antenna maximum voltage limit will be limited. The J-port antenna was tested to 50 kV on the PPPL test stand and the feedthrus were tested to 65 kV. Here the maximum antenna voltage may be probed. In addition, the maximum voltage limit with TF or vertical field present will be investigated. The maximum antenna voltage is expected to degrade when the RF E-field is parallel to the external B-field. Scan B-field to explore B-field dependence.

### 3.2 Plasma maximum voltage and power limit

Find an operating space where the plasma loading is light and operate with maximum power (maximum voltage limit). To determine power limit, maximize the injected power into EDA H-mode.

### 3.3 Plasma response

Using $B_T=5.2 \text{T}$, $I_p=0.8$, 1.0 MA and 1.2 MA, $n_{04} \sim 1 \times 10^{20} \text{m}^{-2}$ discharges, measure the heating efficiency and characterize impurity generation for D, E, and J-port antenna for moderate power (1.5 MW). When available characterize the heating efficiency and impurity generation with $(0,\pi,\pi,0)$ and $(0,\pi/2,\pi,3\pi/2)$. In addition, characterize the loading for 100 kW to 500 kW in the above discharges. The loading for high power discharges will also be documented. Using D($^3\text{He}$), a similar set of discharges will be investigated at 8 T. Additional knobs for varying plasma response and loading are right gap, plasma current, and resonance position (magnetic field).

### 4. Resources

#### 4.1 Machine and Plasma Parameters

Give values or range for:

- **Toroidal Field**: 4.6, 5.2, 8 T
- **Plasma Current**: 0.6-1.5 MA
- **Working gas species**: D, with different concentrations of H and $^3\text{He}$ minority
- **Density**: $n_e = (1-2) \times 10^{20} \text{m}^{-3}$ typical
- **Equilibrium configuration** (if possible, refer to database equilibria): lower single null or inner-wall limited, centered on midplane, $sim1 \text{cm outer gap}$
- **Pulse length, typical current & density waveforms, etc.** Refer to database or sketch desired waveforms: current flat-top up to 1.0 sec
4.2 Auxiliary Systems

RF Power, pulse length, phasing: up to full power

Pellet Injection (species): none

Impurity blow-off injection: none

Special gas puffing: D/H/\(^3\)He

Other:

4.3 Diagnostics

List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

All RF related diagnostics plus standard plasma diagnostics. In particular, H, \(^3\)He, and impurity fraction are important.

4.4 Neutron Budget

Estimate the neutron dose rate at the site boundary. Give basis for estimate. (Once some experience has been gained a standard formula will be provided for estimating dose rates.)

Less than \(5 \times 10^{13}\) per shot.

5. Experimental Plan

5.1 Run sequence plan

Specify total number of runs required, and any special requirements, such as consecutive days, no Monday runs, extended run period (10 hours maximum), etc.

Avoid destructive antenna events. Avoid boronization.

5.1.1 Vacuum characterization

Use short pulses (<10 msec) to reach 40 kV. (1/2 day each system)

Lower the voltage (power) to 25 kV and increase the pulse width until a pulse width of 0.5 sec is reached. Then, increase the power until 40 kV is reached. (1/2 day each system)

After the campaign, repeat this process to characterize voltage handling capability. If the maximum voltage limit appears to be > 40 kV, short pulses will be used to investigate the maximum limit. (1 day total)

In addition, the maximum voltage limit with TF or vertical field present will be investigated. Scan B-field to explore B-field dependence. (2 days)
5.1.2 Plasma maximum voltage and power limit

Fiducial discharge: $B_T=5.2$ T, $I_p=1.0$ MA, $n_{l04} \sim 1 \times 10^{20} m^{-2}$ or $B_T=4.6$ T, $I_p=1.0$ MA, $n_{l04} \sim 1 \times 10^{20} m^{-2}$ for 70 MHz.

For maximum voltage, seek ELM-free like plasmas and can be accomplished in piggy back. For maximum power, seek EDA discharges. For J-port, document limit with both 70 and 78 MHz.

5.1.3 Plasma response

J: 78 MHz

Strong absorption scenario:

Using $B_T=5.2$ T discharges, measure the heating efficiency and characterize impurity generation for D, E, and J-port antenna for moderate power (1.5 MW). Characterize the loading 100 kW to 1.5 MW in the above discharges. The loading for high power discharges will also be documented. Investigated loading and impurity characteristics as a function of right gap (0.5-2. cm), density (8,1.0,1.2 m$^{-2}$), toroidal field (4.5-6.3 T), and plasma current ($I_p=0.8,1.0,1.2$ MA)

Weak absorption scenario:

Using $B_T=8$ T discharges, measure the heating efficiency and characterize impurity generation for D, E, and J-port antenna for moderate power (1.5 MW). Characterize the loading 100 kW to 1.5 MW in the above discharges. The loading for high power discharges will also be documented.

When available characterize the heating efficiency and impurity generation with $0,\pi,\pi,0$ and $0,\pi/2,\pi,3\pi/2$. In addition, characterize the loading 100 kW to 1.5 MW in the above discharges. The loading for high power discharges will also be documented. Using $D(\He$), a similar set of discharges will be investigated at 8 T.

5.2 Shot sequence plan

For each run day, give detailed specification for proposed shot sequence: number of shots at each condition, specific parameters and auxiliary systems requirements, etc. Include contingency plans, if appropriate.

6. Anticipated Results

Discuss possible experimental outcomes and implications. Indicate if the program may be expected to lead to publications, milestone completions, improved operating techniques, etc. Indicate if the experiments are intended to contribute to a joint research effort, or an external database.

1. Determine whether modifications were successful on D, E and J-port antennas. 2. Will the J-port antenna operate in current drive phase. 2. Results will be presented at IAEA.

7. References

Include references both to external and internal literature or communications which bear on this proposal. See Section 2.