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JET-EP ITER-Like ICRF Antenna

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Abstract. Whereas the essential components for power generation and transmission on an ITER-sized ICRF plant are readily available, or only require modest extrapolation of present day ICRF systems, the IC launching structure itself is regarded as needing development, validation and convincing demonstration. During the ITER-EDA, the design requirements of the Next Step device have resulted in increasingly higher values for this power density, going from less than 1 MW/m² with the launcher integrated in the blanket, to presently about 10 MW/m² for the present ITER, where the launcher is required to fit inside an equatorial port. The presently proposed JET-Enhanced Performance project ITER-like ICRF launcher, due for installation during the 2004 shutdown, mainly features a high power density of about 8 MW/m² at a relevant coupling of 4 Ohm/m and IC heating scenarios at frequencies from 30 to 55 MHz for pulses up to 20 seconds with a tolerance to load variations due to ELMs.

DESIGN BASIS

The high power density is achieved by using relatively short antenna central conductors (straps) with low inductance as compared to most present day experiments. It has to be noted that antennas based on ORNL's Resonant Double Loop (RDL) design, such as on Tore Supra (F), have a so-called virtual ground point located at the center of the strap and therefore could be considered as a combination of two conventional short-circuited straps of half the length of the RDL strap. Table 1 compares the parameters of the proposed JET-EP ITER-Like antenna to those of the former JET A1 antenna. The short length and low inductance of the strap keeps the voltage at the strap feeding point below 25 kV at 55 MHz and 4 Ohm/m for the required power density (fig 1).

The ELM resilience is achieved using an optimized conjugate-T matching circuit. Two branches feeding similar straps through matching elements that are set to have conjugate complex admittances connected together at a T-junction. The reactive parts are cancelled and the characteristic impedance of the feeding transmission line is optimized such that for the expected variations of the coupling to the plasma the combined real parts of the admittance vary as little as possible. This allows to stay within the JET generator specifications (VSWR < 1.5) for a coupling varying from 2 to 15 Ohm/m (fig 1).

TABLE 1. Comparison of the straps of the new JET-EP Antenna and the JET A1 Antenna

	JET-EP	JET A1
Power / Strap x number of straps	1 MW x 8	1 MW x 4
Strap Length [m]	0.27	0.55
Strap Width [m]	0.21	0.15
Coupling [Ohm/m]	4	7
Specific Inductance [nH/m]	200	265
Specific Capacity [pF/m]	145	135
Feeder Length in Antenna Box [m]	0.25	0.70
Characteristic Impedance [Ohm]	20	30

The experience on JET with the A2 antenna, on Asdex-Upgrade and Tore-Supra has revealed the necessity of defining low inductance RF grounding connections of Faraday Screen (FS) to the antenna box and of this box to surrounding structures. The usefulness of being able to slightly trim the position of the antenna front face with respect to adjacent main protection poloidal limiters was shown on Tore-Supra and in the present design this distance can be trimmed on a shot to shot basis up to 25 mm.

The side walls of the antenna box made of corrugated thin Inconel sheets are kept closed all the way up to the front face and the beryllium FS is bolted directly to the antenna box without resistors such as used on the JET A1 and A2 antennas. This Faraday Screen can be removed and the antenna box's modest private limiter repositioned during a shutdown to explore possibilities to move the straps closer to the plasma for increased coupling when the FS is removed. The beryllium Faraday shield is purely horizontal (not aligned to the total magnetic field) and grounded at the central septum.

ANTENNA LAYOUT AND MATCHING

The present reference design option is a variation of the RDL launchers, such as on Tore Supra, which have achieved the highest power density of 12 MW/m² among present day ICRF systems. The reactive tuning elements, the capacitors, are moved away from the strap ends, where they support the strap on TS, to the feeder region of

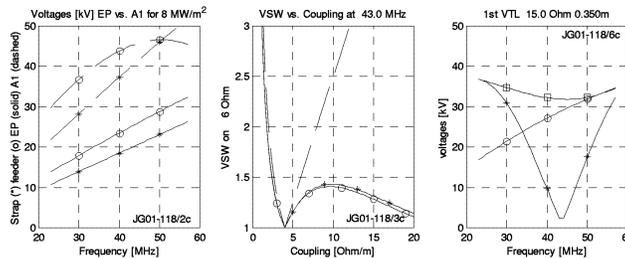
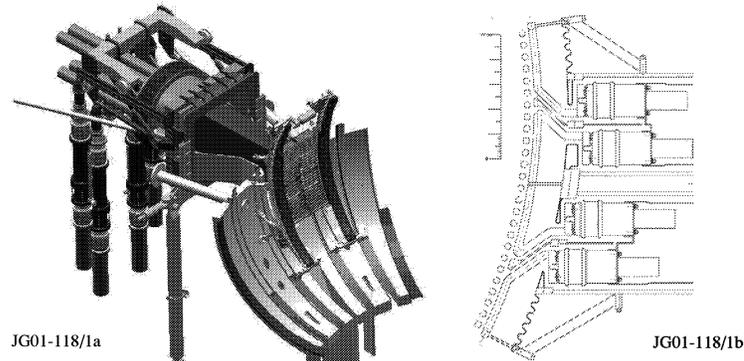


FIGURE 1. [Left] Strap (*) and feeder (o) voltages for the JET-A1 (dashed) and the JET-EP antenna (solid) at equal power density of 8 MW/m². [Middle] Load tolerance of the conjugate-T matching for 6 Ohms for the reference (*) and fall-back (o) options compared to that of a classical lossless matching 2-port (dashed). [Right] Voltages for the fall-back option : maximum voltages on the 15 Ohm 35cm long 1st section of the VTL (o), on the 30 Ohm part of the VTL and feeding transmission line to the matching capacitors () and the voltage at the window at 2.20m from the 15 Ohm VTL (*).



the double loop, allowing simple and ITER relevant pair of mechanically self-supported (halved) straps. The straps will be fed by as short as possible low impedance feeders directly from the matching capacitors.

The impedance transformer from 6 Ohm (impedance to which the resonant circuit is matched to) to 30 Ohms (feeding transmission lines) is located directly after the capacitors and fits inside the VTL area in the case of a two-stage transformer. Preferred option is a three stage transformer in which case the vacuum window may need to have the characteristic impedance of the last stage (about 25 Ohm) and this last stage is implemented in the pressurized transmission line section following the vacuum window. The water cooling for the capacitors and control rods of the capacitors are entered through a rear end stub whose inductance is neutralized by a variable capacitor (RF-choke). This stub is also instrumental to replace the capacitors in case of failure.

If the insertion of the water-cooled capacitors inside the JET vessel turns out to be problematic for what concerns reliability, safety, achievable pulse length and or

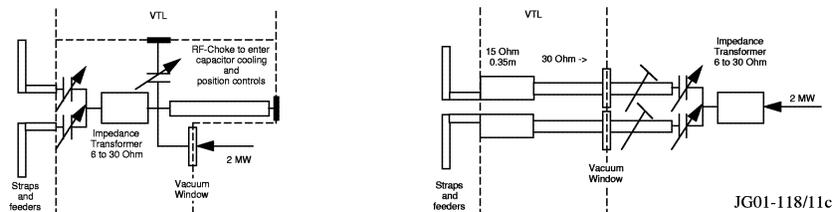


FIGURE 3. reference in-vessel (left) and fall-back ex-vessel (right) matching options

mechanical assembly a fall back option is considered placing reactive matching elements outside the torus vacuum. The maximum system voltages are estimated to be slightly above 30 kV at the end of the feeders for the reference option (with 35 kV across the capacitors) as well as for the fallback option, and 35 kV along an optimized VTL for the fall back solution. Electric fields are kept in both options to be below 2 kV/mm.

R&D ACTIVITIES

Improvement of the reliability of the bellows inside the capacitors : The CuBe bellows is replaced by an Stainless Steel bellows coated with copper. Prototype bellows have been tested up to 11500 full cycles³ (about 5000 partial cycles were estimated to be necessary for a 2 year operation on JET-EP). Full prototype capacitors are to be tested at nominal current and voltage in a high Q resonator at Cadarache (CEA, Fr).

An assessment of the cooling requirements for the capacitor is being carried out : it would appear that cooling of the variable end with the bellows of the capacitor while keeping the surrounding VTL cooled at 50 °C will permit to leave the fixed end of the capacitor connected to the antenna straps un-cooled. This greatly simplifies the design and e.g. removes the need for in-vessel (remote handling) welding of coolant conduits.

Testing of the finger contact between the straps and the capacitors : It is proposed to test two solutions for this contact on the high Q resonator of CEA at Cadarache, the first one based on the standard 'Multi-Lame' contact and a second 'radial contact' that would be better suited for the insertion and removal of the capacitors.

Low Power Mock-up : a low power mock-up has been built to assess the influence of the asymmetry (fig 2) on the matching properties of one resonant circuit as well as possible toroidal cross coupling between adjacent pairs of straps².

High power Prototype : A full scale quarter of the total antenna will be built by US ORNL and PPPL (US) to test the voltage stand-off of the straps, feeders as well as the current capability of the finger contacts and the thermal properties of the capacitors.

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