Status of the ITER IC H&CD System

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Status of the ITER IC H&CD System

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Abstract. The ITER Ion Cyclotron Heating and Current Drive system will deliver 20MW of radio frequency power to the plasma in quasi continuous operation during the different phases of the experimental programme. The system also has to perform conditioning of the tokamak first wall at low power between main plasma discharges. This broad range of requirements imposes a high flexibility and a high availability. The paper highlights the physics and design requirements on the IC system, the main features of its subsystems, the predicted performance, and the current procurement and installation schedule.

Keywords: ITER, Ion Cyclotron Heating and Current Drive, IC H&CD, antenna array, load-resilient matching.
PACS: 52.35.Hr, 52.50.-b, 52.50.Qt

SYSTEM REQUIREMENTS

The ITER Ion Cyclotron Heating and Current Drive (IC H&CD) system is to be designed to couple 20MW of power in quasi-CW operation (pulses up to 3600s) in the frequency range 40 to 55MHz, for a variety of ITER plasma scenarios, see Table 1. The system must also provide robust coupling in the presence of ELMs, and be designed to perform wall conditioning at low power (≤ 3MW) between plasma shots.

Two antennas will be installed in equatorial ports, each antenna being designed for a 20MW capability (with a 45kV limit on the system). Using two antennas strongly

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reduces risks to system performance associated with (1) large uncertainties on ITER edge density profiles, hence on coupling; (2) RF voltage standoff (reduced risk of arcing ⇒ accrued reliability); (3) dissipation (RF current) limit in CW operations; and (4) RF sheath dissipation per antenna ⇒ reduced associated heat loads. This will allow delivering nominal power in a wide range of plasma scenarios. Having two antennas increases the versatility of the system, e.g. by allowing dual frequency operation, and increases its availability in case of maintenance operations. The second antenna is a natural step in the direction of a future upgrade. Up to 40MW could be coupled at a later stage with the two antennas by increasing the generator power. The meaningful extent of this upgrade depends on the plasma loading range that will effectively be achieved, i.e. to be assessed after acquisition of sufficient experimental information. Current predictions with TOPICA [1] indicate that powers in the range of 30 to 45MW could be coupled with two antennas, see below and [2-4].

TABLE 1. Main ITER IC H&CD scenarios.

Resonance	MHz	Comments
$2\Omega_T = \Omega_{3He}$	53	Second harmonic tritium + minority heating of ^{3}He to optimize ion heating*
FWCD	55	On axis current drive*
Ω_{3He}	45	Minority ion current drive at sawtooth inversion radius (outboard)*
Ω_{3He}	40 - 55	Minority heating of ^{3}He in H, D, ^{4}He or DT (B_T= 3.7 to 5.3T)
Ω_H	40 - 55	Minority heating of H in D, He or DT at reduced field (B_T=2.5 to 3.8T)

* at the nominal magnetic field (B_T=5.3T).

SYSTEM LAYOUT

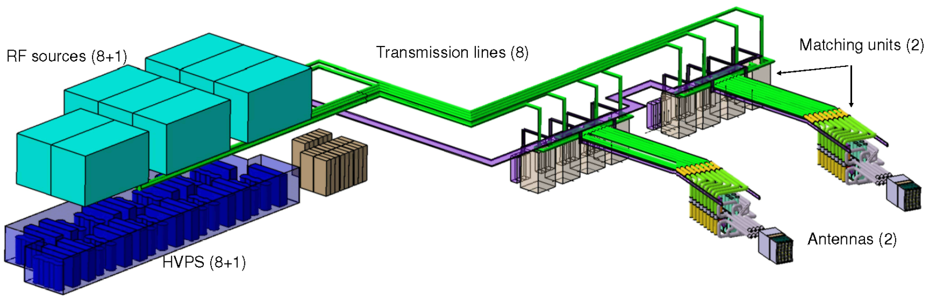

FIGURE 1. Layout of the ITER ICRH System

The general layout of the system is illustrated on Fig. 1. The main features of the subsystems are as follows:

1- High voltage power supplies (HVPS): based on Pulsed Step Modulator design, with a large number of low-voltage (<1 kV) modules stacked in series, which can be switched on/off individually for fine regulation of the output voltage. The issues are: the power per unit, layout and integration in the available space, and the tap feed of the anode driver at intermediate voltage level.

2- RF sources: specified to deliver either 2.5 MW in CW operation on a VSWR=2 load in the band 35-65 MHz, or 3 MW CW on VSWR=1.5 in the antenna design band 40-55MHz (in both cases for any phase of the reflection coefficient). The required instantaneous bandwidth at -1dB is ±1MHz. The sources will use two parallel amplifier chains with a combining circuit. Anode voltage dynamic control is required to adjust dissipation as a function of the phase and amplitude of reflection coefficient changes. The issues are: high power tube capabilities and tube qualification, stability of the combining circuit, and bandwidth.

3- Transmission lines and matching systems [5]: use coaxial lines rated for CW transmission of up to 2.5 MW per line at VSWR ≤ 2. These lines will require active water cooling of external conductors, and dielectric gas at 3 bar will be circulated between inner and outer conductor to cool the inner conductor. A component testing activity has been launched in the USA in 2008. Coaxial switches will allow to connect any RF source to a high power load for commissioning, testing and maintenance. The matching system will use the 'ELM dump' scheme based on hybrid splitters to be installed in the Assembly Hall (the conjugate-T approach being a backup option). Decouplers will connect adjacent circuits in order to cancel dominant mutual reactive coupling, equalize strap currents and line powers in various spectrum configurations. The matching and decoupling networks will be located in the port cells. The issues are: (i) high VSWR between matching system and antenna, (ii) dense port cell layout.

4- Antennas [6]: each antenna shall comprise an array of 6 poloidal by 4 toroidal short radiating straps. The 24 straps are connected in 8 poloidal triplets. The radiated power spectrum is adjustable by control of toroidal phase differences between antenna voltages or currents, and by control of the voltage or current ratios between columns of straps. Each antenna port plug is composed of a support structure, a Faraday shield, the RF structure (antenna radiating box, straps, in-vessel vacuum transmission lines, vacuum windows), a grounding system, neutron shielding structures, diagnostics, and a local plant controller.

PREDICTED PERFORMANCE

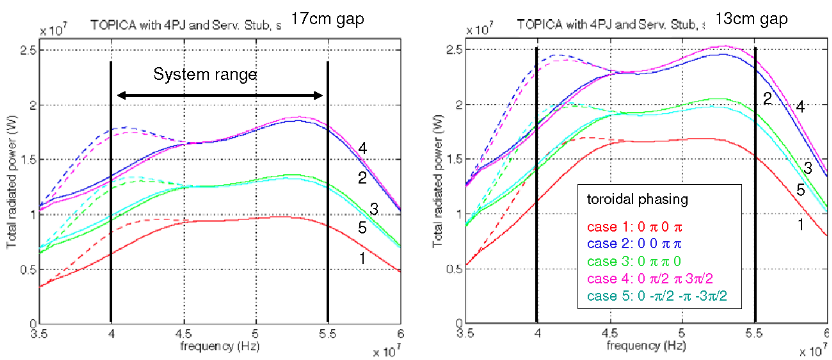

FIGURE 2. Predicted maximum coupled power per antenna vs frequency for the main array toroidal phasings. Steep SOL density profiles are assumed as per [7]. LCFS to first wall gap: 17cm (left), 13cm (right). Continuous lines: maximum voltage Vmax limited to 39kV on the whole system. Dashed lines: Vmax ≤ 39kV on the feed lines but allowing up to 45kV on the vacuum transmission lines at 40MHz.

Figure 2 shows the simulated maximum coupled power per antenna based on TOPICA results [4], assuming a 39kV maximum voltage (i.e. below the design specification of 45kV). Note that 42kV have been achieved on the JET-EP system [8], and that 45kV is the operational limit used on Tore Supra [9]. For large gap between plasma last closed flux surface (LCFS) and first wall, 20MW can be coupled with margins with 2 antennas for all phasings but dipole ($0\pi0\pi$); in dipole, 20MW is only obtained between 45 and 55MHz and there is a power derating between 40 and 45MHz. For smaller gap, 20MW is achievable with all phasings over the whole frequency range, with comfortable margins. Benchmarking of the TOPICA simulations against JET data looks promising and, if confirmed, will significantly consolidate these predictions [10].

R&D PROGRAMME, PROCUREMENT STRATEGY, SCHEDULE

An R&D programme has been set up to support the design phase of the components. This programme will develop prototypes or perform tests in the areas of the RF vacuum windows, the Faraday shield, transmission line and matching components, low power mock-up measurement of the full array, and the choice of the high power tube for the RF source.

The IC H&CD system is divided in four packages, but the overall activity will be managed through a new Integrated Product Team grouping all Domestic Agencies (DA) involved in its procurement. The antennas will be procured by EU-DA (built to print package, ITER providing a complete design and being fully responsible for performance and safety aspects), the transmission lines and matching systems by US-DA (functional specifications package, ITER providing a conceptual design with technical specifications), RF sources and HVPS by IN-DA (also at functional specifications).

The present IO schedule is being revisited but at present the option considered is one antenna being installed in 2020, requiring 4 RF sources and corresponding power supplies; the second antenna being installed in 2022 with the remaining RF sources. The procurement scheme is based on signature of RF sources and HVPS procurement arrangements (PA) with IN in summer 2009, PA signature with US on the transmission lines and matching systems end 2009; signature of a task with EU on antenna design, with R&D contracts supporting the activity, to establish a build-to-print design by the end of 2012; signature of the antenna PA in 2013.

The equipment will be tested in each DA before shipment to the ITER site. IO will provide the installation work force under DA supervision. Commissioning and final acceptance tests will be a shared collaboration between IO and DAs.

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