Status of the ITER ICRF system design - 'Externally Matched' approach

P U Lamalle[1], M Shannon[2], A Borthwick[2], S Brons[3], B Chuilon[2], P Dumortier[1], F Durodié[1], M Evrard[1], R Goulding[4], F Louche[1], A Messiaen[1], M Nightingale[2], D Swain[4] and M Vervier[1]

[1]Laboratory for Plasma Physics[§], Association EURATOM-Belgian State, Royal Military Academy, B-1000 Brussels, Belgium. [2]UKAEA/EURATOM Fusion Association, Culham Science Centre, Abingdon OX14 3DB, U.K. [3]FOM IPP Rijnhuizen[§], Association EURATOM-FOM, The Netherlands. [4]Oak Ridge National Laboratory, TN 37831-6169, Tennessee, USA. [§]Partners in TEC.

Abstract. The design of the ITER ICRF system has been under revision for several years. The paper presents the status of the design proposal based on a 24 strap antenna plug (6 poloidal by 4 toroidal short radiating conductors) in which the straps are passively combined in 8 poloidal triplets by means of 4-port junctions. These triplets are connected in parallel pairwise through matching elements to form 4 load-resilient conjugate-T circuits. All adjustable matching elements are located outside the plug, i.e. in the ITER port cell and in the generator area.

Keywords: Ion Cyclotron Resonance Frequency, ICRF, antenna array, load-resilient impedance matching, ITER.
PACS: 52.35.Hr, 52.50.-b, 52.50.Qt

INTRODUCTION

A revision of the ITER ICRF system design has been proposed in [1, 2], which addresses several difficulties identified with the reference 2001 design [3] (see e.g. the discussion in [4]), whilst preserving the attractive features of a wide frequency range (40-55MHz), high power density and resilience to edge-localized modes (ELMs). The paper presents the status of this revised concept, which has been considerably detailed and has evolved towards integration in ITER over the last two years [5, 6]. The design exclusively uses ex-vessel adjustable components, to be adequately scaled and adapted from existing commercial components for high-power, long-pulse specifications. Its RF characteristics and circuit matching behaviour have been analyzed in detail. Key mechanical aspects have been established and fabrication, assembly and maintenance aspects have been incorporated.

MAIN RF FEATURES OF THE DESIGN

The antenna array is composed of 6 poloidal by 4 toroidal radiating straps (Fig.1), each fed by a strip line connected to a coaxial line section. Increasing the number of straps and decreasing their length yields lower feeder voltages than in the 2001 design. Six poloidal straps was found the best compromise for the ITER plug dimensions.

The straps are grouped in poloidal triplets by means of in-vessel 4-port junctions (4PJ) connecting the associated coaxial lines. This reduces the number of independent mutually coupled circuits and matching elements by a factor 3, and thus considerably

CP933, *Radio Frequency Power in Plasmas,* edited by P. M. Ryan and D. A. Rasmussen

simplifies the array matching. Having only 8 feed lines increases the volume available for neutron shielding materials and has allowed introduction of ‘dog legs’ to reduce neutron streaming [6]. Each line has a pair of double conical vacuum window barriers as per the ITER specifications. 16 vacuum windows are required in total, plus an additional 8 window support assemblies within the Forward Housing Modules (FHM, Fig.1). The 4PJ also achieves a passive current control for each strap triplet by splitting the current in 3 in-phase components of similar amplitudes. It is located near the first voltage antinode at midband, a configuration which reduces the standing wave ratio (SWR) by a factor 5 at midband and ≥3 at the band edges.

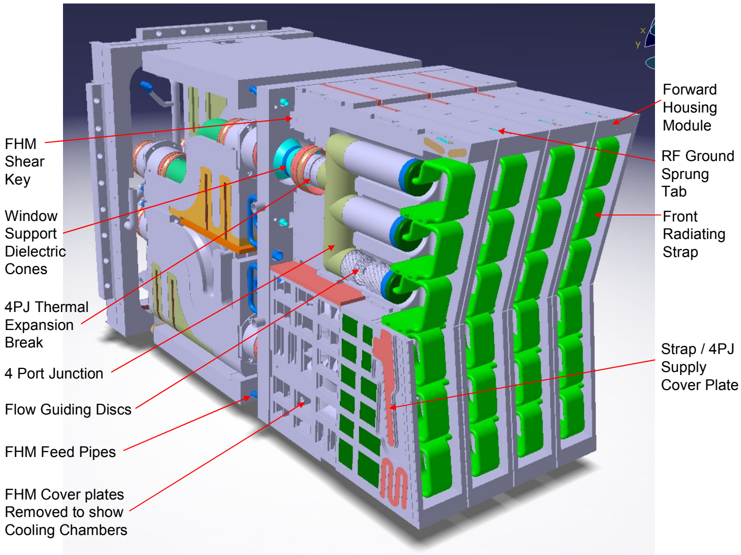

FIGURE 1. Layout of the front part of the proposed ICRF antenna plug, from the CATIA reference model [6]. Note the 6x4 straps. One of the eight 4-port junctions connecting straps in triplets is visible.

The strap triplets are connected in poloidal pairs through matching networks located in the port cell to form 4 “conjugate T” (CT) load-resilient circuits, see Figs. 2 and 3. RF power is delivered from the generator hall by 4 transmission lines (TLs) at low SWR (≤2.5), with a nominal power ≈6MW each. All adjustable elements are in pressurized line sections located in the ITER ICRF port cell and in the generator area, i.e. they are accessible for servicing, repair or replacement without intervention on the torus, on the antenna plug or in the port interspace. There are no sliding contacts in vacuum. This layout allows the incorporation of additional RF functions between the matching system and the antenna plug: firstly pre-matching, which reduces the SWR by another factor 2.5 over the frequency band and secondly decoupling, which cancels the dominant mutual susceptances between the straps. Flexibility in the matching layout is also an asset given the currently limited operational experience with the proposed CT matching scheme: if needed, modifications could readily be implemented during detailed design after high power operation of the JET ITER-like antenna [7, 8] on plasma. With the CT circuits external to the port plug, directional couplers and redundant voltage probes in the pressurized TLs provide all the required RF measurements for matching control. Voltage probes in the antenna plug are to provide additional diagnostics for arc detection and data consistency checks.

More details will be found in [5], matching and RF circuit simulations in [9, 10].

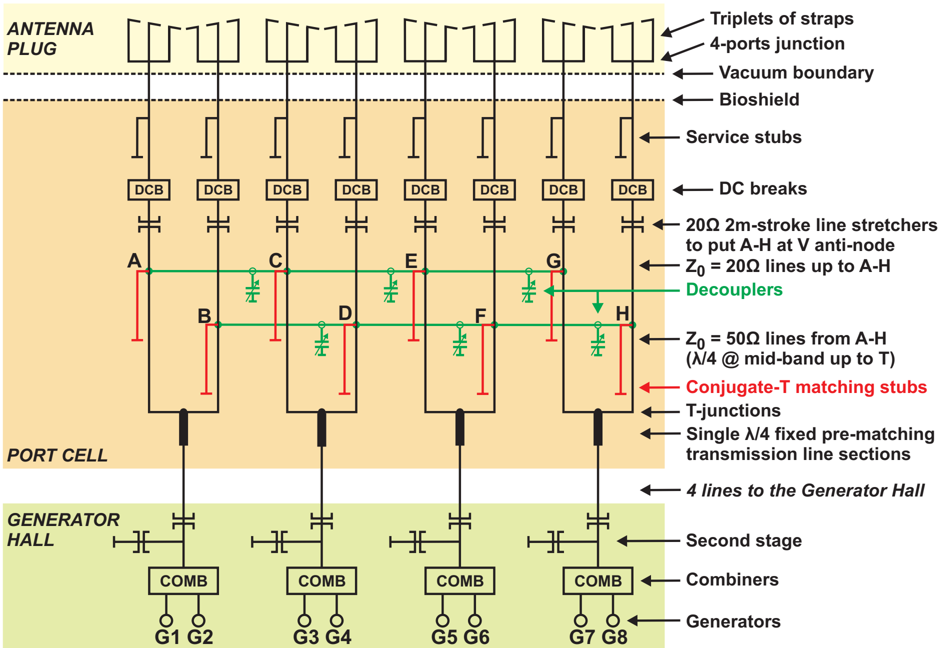

FIGURE 2. Schematic layout of the RF transmission and matching circuit.

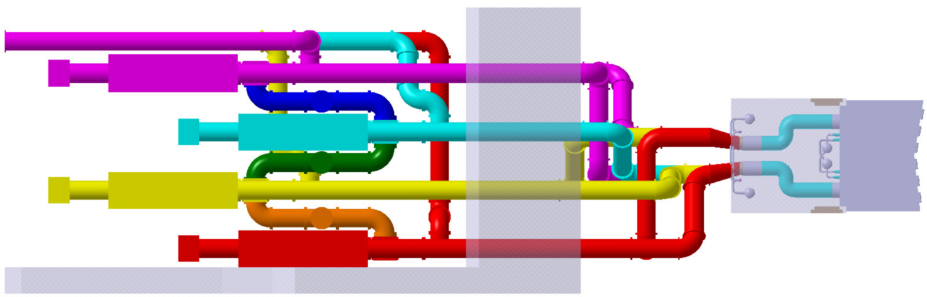

FIGURE 3. Schematic layout of the port cell matching and decoupling units (to be optimized).

Several design features require attention during the detailed design phase: *(1)* The vertical septa between straps should be thinned compatibly with the Faraday shield design to increase antenna loading. *(2)* The 4PJ design requires due care to achieve the desired RF performance at the band edges. It must be fabricated at the desired RF specification, using electromagnetic simulations and mockup measurements to finalize the coaxial feeder lengths. *(3)* The antenna conductor shapes will be optimized to improve loading by the plasma and reduce electric fields. *(4)* The high SWR line sections between CTs and 4PJs carry large RF currents (maximum ~2.6kA peak) and require adequate cooling, to be introduced via fixed service stubs.

MECHANICAL DESIGN OF THE PLUG

Fabrication, assembly and maintenance considerations were included early in the conceptual design to minimise later re-work. A modular approach was adopted to facilitate staged assembly and testing and allow for simplified maintenance operations [6], see Fig.1. Thermal, disruption and preliminary neutron shielding analyses have been performed with favourable results, achieving ITER design targets in virtually all areas. No major drawbacks have been identified which would prevent integration of the system in ITER. Some areas will require improvements during detailed design: *(1)* A strict design limit of 45Te for the port plug dry weight is difficult to achieve given the counter-acting requirement of a dose rate at the port plug rear <100μSv/hour after 10^6s. This requires a highly optimised neutronic shielding arrangement with a high water fraction. The current design is 20% overweight, however significant areas for further optimisation have been identified. *(2)* The favored double conical dielectric vacuum window as used on JET-EP [7] utilises the particular properties of Ti alloy in conjunction with alumina to produce a pre-compressed assembly. The susceptibility of Ti alloy to hydrogen embrittlement however, has necessitated a search for an alternative dielectric / metallic housing pairing demonstrating a similar pre-compression during the bonding phase. Finite element studies have revealed BeO and Be-BeO metal matrix composites as the most promising candidates. *(3)* Creating a cooled structure and outer conductor surface around the 4PJ shape necessitates an assembly in two halves. This Forward Housing Module assembly has been designed to achieve a high water fraction for neutronic and weight reasons, whilst providing the cooling paths needed to maintain neighboring components at acceptable temperatures. Investment casting is being considered as the basic fabrication method for these components. *(4)* The TL core conductor receives large thermal loads, must be stiff and precisely aligned. Coolant is supplied and returned from one side. The design adopts a hollow pressure bearing outer shell, filled with mass manufactured flow guide disks. Coolant is forced through helical flow paths. This simplifies assembly, enhances convection and neutron shielding. The laminations suppress eddy currents, thereby reducing disruption loads, whilst obtaining a ~20% weight saving.

ACKNOWLEDGMENTS

This work was carried out within the EFDA under Task TW5-TPHI-ITERDES, and was partly funded by the UK EPSRC and EURATOM. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

REFERENCES

1. P. Dumortier *et al.*, Final report on Task FU05-CT 2002-00094 (EFDA/02-675), Laboratory Report n°121, Laboratory for Plasma Physics, Royal Military Academy, Brussels, Belgium (2004).
2. P. Dumortier *et al.*, in "Radio-frequency Power in Plasmas", 15th Top. Conf. on Radio-Frequency Power in Plasmas, Moran, USA, AIP Conf. Proceedings **694** p.94 (2003); A.M. Messiaen *et al.*, *ibid.* p.142.
3. ITER Detailed Design Description, Ion Cyclotron Heating and Current Drive System, July 2001.
4. G. Bosia, Nucl. Fusion **46** S540-9 (2006).
5. P. U. Lamalle et al., Final report on Contract EFDA/05-1269, Laboratory Report n°129, Laboratory for Plasma Physics, Royal Military Academy, Brussels, Belgium (2007).
6. M. Shannon et al., Final Report "CD/ITERICRH/T/005 UKAEA activities in support of the design of the ITER ICRF antenna for external matching concept", March 28, 2007.
7. F. Durodié et al., Fusion Eng. and Design 74 223 (2005) (Proc. 23rd SOFT, Venice, Italy, 2004)
8. F. Durodié et al., these Proceedings.
9. A. Messiaen et al., these Proceedings.
10. P. U. Lamalle et al., Final report on Contract EFDA/05-1334, Laboratory Report n°130, Laboratory for Plasma Physics, Royal Military Academy, Brussels, Belgium (2007).