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Status of R&D activity for ITER ICRF power source system

Aparajita Mukherjee [a,*], Rajesh Trivedi [a], Raghuraj Singh [a], Kumar Rajnish [a], Harsha Machchhar [a], P. Ajesh [a], Gajendra Suthar [a], Dipal Soni [a], Manoj Patel [a], Kartik Mohan [a], J.V.S. Hari [a], Rohit Anand [a], Sriprakash Verma [a], Rohit Agarwal [a], Akhil Jha [a], Fabienne Kazarian [b], Bertrand Beaumont [b]

[a] *ITER-India, Institute for Plasma Research, Bhat, Gandhinagar–382428, India*
[b] *ITER Organization, CS 90 046, 13067 Sain-Paul-Les-Durance, France*

HIGHLIGHTS

- R&D program to establish high power RF technology for ITER ICRF source is described.
- R&D RF source is being developed using Diacrode & Tetrode technologies.
- Test rig (3 MW/3600 s/35–65 MHz) simulating plasma load is developed.

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ABSTRACT

India is in-charge for the procurement of ITER Ion Cyclotron Resonance Frequency (ICRF) sources (1 Prototype + 8 series units) along with auxiliary power supplies and Local Control Unit. As there is no unique amplifier chain able to meet the output power specifications as per ITER requirement (2.5 MW per source at 35–65 MHz/CW/VSWR 2.0), two parallel three-stage amplifier chains along with a combiner circuit on the output side is considered. This kind of RF source will be unique in terms of its stringent specifications and building a first of its kind is always a challenge. An R&D phase has been initiated for establishing the technology considering single amplifier chain experimentation (1.5 MW/35–65 MHz/3600 s/VSWR 2.0) prior to Prototype and series production. This paper presents the status of R&D activity to resolve technological challenges involved and various infrastructures developed at ITER-India lab to support such operation.

1. Introduction

ITER require 20 MW of RF power to a variety of ITER plasmas in the Ion Cyclotron (IC) frequency range for heating and driving plasma current [1]. Wall conditioning using the same system is also anticipated in between the plasma shots at lower power level. The IC system is composed of 2 antenna port plugs, transmission lines, main and pre-matching units, RF power sources and High Voltage Power Supplies (HVPS) along with controls. Each antenna will be fed by 4 number of RF sources connected with 8 transmission lines and associated matching units [2]. The entire system will be developed/procured by three Domestic Agencies (DA) along with ITER Organization (IO). The antennas will be procured by EUDA as Built-to-Print (BTP) package, transmission line and matching systems by USDA as Functional Specifications (FS), RF sources and part of HVPS by INDA as Functional Specifications (FS) and rest of the HVPS by IO as Functional Specifications (FS).

Under RF source package, INDA is responsible for total 9 number of RF sources along with auxiliary power supplies and controls. Each source shall have the power handling capability of 2.5 MW/CW at VSWR 2:1 in the frequency range 35–65 MHz or 3.0 MW/CW at VSWR 1.5:1 in the frequency range 40–55 MHz, along with other stringent requirement. There is a certain gap in demonstrated capability vs. ITER need. CPI make Tetrode tube 4CM2500KG used for KSTAR ICRF facility for generating 1.9 MW for 300 s in the frequency range 30–60 MHz [3]. Thales make Diacrode TH628 tested for 1 MW/1000 h at 200 MHz [4]. Both the systems were tested on dummy load. Therefore, specification for ITER ICRF Source is unique in terms of its stringent requirement and building of 1st of its kind is always a challenge.

* Corresponding author. Tel.: +91 7923269541.
E-mail address: aparajita.mukherjee@iter-india.org (A. Mukherjee).

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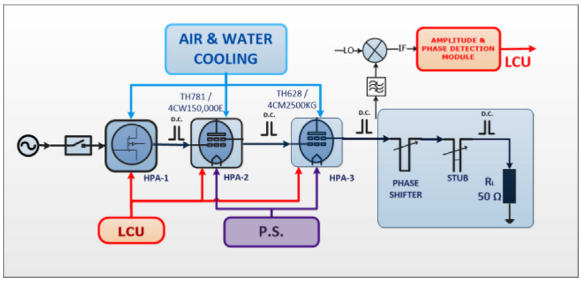

Fig. 1. Block diagram of R&D RF source with test rig.

To demonstrate the performance of worldwide available high power tubes (Tetrode/Diacrode) for ITER application, an R&D program has initiated, considering single chain experimentation at 1.5 MW/3600 s/35–65 MHz. Based on the outcome of this program, ITER Prototype and 8 numbers of RF sources will be built and will be delivered to ITER organization as in-kind contribution. In the Prototype RF source and subsequent series production, two such single chain of amplifiers will be combined using 4 port wideband power combiner, having coupling 3 ± 0.3 dB in the entire frequency band 35–65 MHz. Minor power imbalance for the two input ports (corresponding to ±0.3 dB requirement at the band edge frequencies) of the combiner will be adjusted by varying output power from the amplifier chains, thus reducing the effort for mechanical changeover of combiner section, during various plasma operating scenarios.

In this paper the present status of various sub-systems of R&D RF source and development program for very high power ITER-like test rig is described.

2. R&D RF source

RF source is consists of different subsystems, like, low power RF section, solid state pre-driver amplifier (HPA1), tube based driver (HPA2) and final stage amplifier (HPA3), Local Control Unit (LCU) and AC/DC Power Supplies. Block diagram of R&D RF source along with high power test rig is shown in Fig. 1.

Gain vs. input as well as output power requirement for various modules is tabulated in Table 1. The estimated gain for solid state based amplifier HPA-1 is higher than the tube based amplifiers HPA-2 and HPA-3. Further, during RF operation, maximum VSWR seen by HPA-2 and HPA-3 may be 1.3:1 and 2:1, respectively, whereas HPA-1 will not face any VSWR situation and will operate always with matched condition. Therefore, input power requirement for targeted output power, say 130 kW (1.5 MW) shall vary from 4.0 kW (29.8 kW) to 6.7 kW (119 kW) for HPA-2 (HPA-3) to accommodate varying impedance seen by the amplifiers during matched to mismatched situation, as shown in Table 1. In R&D phase, the main goal is to qualify the final stage active device, i.e., RF tube, for ITER like application. The major technical challenges are: (1) to deliver constant 1.5 MW output power even with VSWR 2:1 for any reflection phase angle, (2) pulse duration for 3600 s with 25% duty cycle, (3) broad frequency range with accurate instantaneous bandwidth (±1 MHz at 1 dB point), (4) operational problems like, settling of anode voltage, excess anode dissipation etc. during mismatch situation, (5) unwanted oscillation and mode generation during operation, (6) modulation requirement, and (7) system tuning within 180 s.

Table 1
Gain vs. power requirement for various modules.

Module	Max. gain (dB)	Expected gain (dB)	*I/P* power	Max. *O/P* power
HPA-1	71	70	1 mW	10 kW
HPA-2	15	12.9–15.1	6.7–4.0 kW	130 kW
HPA-3	15	11.0–17.0	119.0–29.8 kW	1.5 MW

The driver (HPA2) and final (HPA3) stage amplifiers are being developed by two well-known suppliers (Continental Electronics Corporation, USA and Thales Electron Devices, France) using Tetrode and Diacrode technologies. Tubes and cavities will be integrated in a full amplifier chain developed by ITER-India. Tests under ITER specifications will validate each design.

2.1. Low power RF section

Low power RF section is consist of master synthesizer, RF switch, voltage control phase-shifter, voltage control variable attenuator, etc. Amplitude and phase are the critical parameters which will be controlled and monitored for better operation of RF source. Phase can be controlled from voltage variable phase shifter as well as master synthesizer. Amplitude can also be controlled using voltage variable attenuator as well as synthesizer.

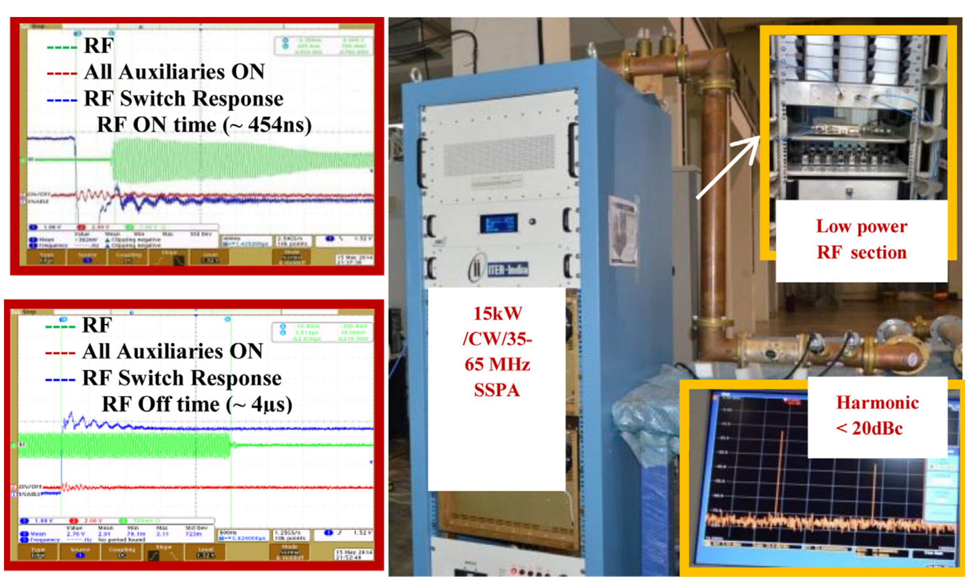

Fig. 2. 15 kW SSPA commissioned successfully.