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Design of high power RF amplifier for 3 MW/CW transmission line test rig

Raghuraj Singh*, Aparajita Mukherjee, Ajesh P., Akhil Jha, J.V.S. Harikrishna, R.G. Trivedi, Kumar Rajnish, Gajendra Suthar, Rohit Anand

ITER-India, Institute for Plasma Research, Bhat, Gandhinagar 382428, India

HIGHLIGHTS

- Test rig for coaxial tx. line components up to 3 MW/45–55 MHz.
- Design of 150 kW/45–55 MHz RF power amplifier.
- Coaxial cavities for high power RF amplifier.

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ABSTRACT

India is developing 2.5 MW RF source at VSWR 2:1 in the frequency range 35–65 MHz for ITER project. Eight such RF sources will generate total 20 MW of RF power for plasma heating and current drive. A large number of high power transmission line components are required for connecting various stages of RF source. To test these passive transmission line components at high power, a 3 MW test facility based on the concept of Traveling Wave Resonator (TWR) is underway. A high power CW RF amplifier is required to feed RF power to 10 dB coupler of TWR. To fulfill the requirement a tetrode based amplifier is designed to operate in class B with optimized efficiency, gain and harmonics level. The detail design is carried out to estimate operational parameters derived from the data sheet of selected tetrode, simulation for RF cavities, power supply requirements and thermal management for CW operation.

1. Introduction

The requirement for ITER Ion cyclotron RF source is to deliver constant output power of 2.5 MW/3 MW with mismatch load conditions, corresponding to voltage standing wave ratio (VSWR) 2:1/1.5:1 during plasma heating and current drive scenarios. The RF power will be transported through 12 in. coaxial transmission line, having 50 Ω characteristic impedance along with an impedance matching network to the antennas, placed inside the ITER machine. The RF power transporting system mainly consists of directional couplers, coaxial elbows, tees, gas barriers, stubs and phase shifters. Problems, such as melting caused by voltage breakdown, have been noticed on these transmission lines, impedance matching network and associated passive components. It is necessary to validate the RF voltage breakdown of all the components used in transporting system to avoid severe damage as the melting, which can lead to a fire, especially during long-pulse operation. Therefore a RF amplifier is designed to feed ∼150 kW RF power in the frequency range of 45 MHz–55 MHz into the 10 dB coupler to get 3 MW circulating power in the TWR [1,2] as shown in Fig. 1 consisting component under test with arc detection facility to switch off RF power quickly to protect the damage of component under test due to voltage breakdown.

The expected gain for the amplifier is around 13–15 dB, therefore, 10 kW Solid State Power Amplifier (SSPA) is chosen to drive the amplifier. The amplifier consists of low power RF section, 10 kW SSPA, 150 kW amplifier stage, auxiliary & high voltage power supplies and monitoring & controls as shown in Fig. 2. Further the amplifier needs air and water cooling for thermal management, support structure, dummy load etc.

The tetrode and its operational parameters for the amplifier are described in Section 2. Description of circuit, cavities and simulation results is presented in Section 3. In Section 4, description of equivalent network is introduced. Section 5 presents the summary.

* Corresponding author.
E-mail addresses: raghuraj.singh@iter-india.org, raghuraj@ipr.res.in (R. Singh).

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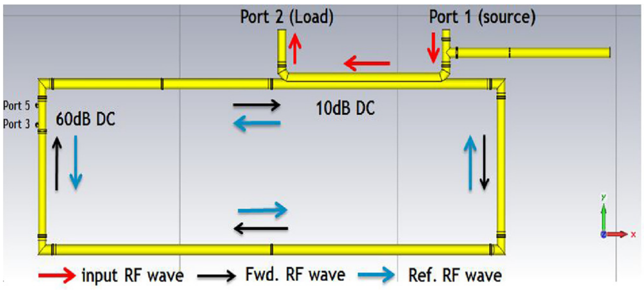

Fig. 1. Typical setup of traveling wave resonator.

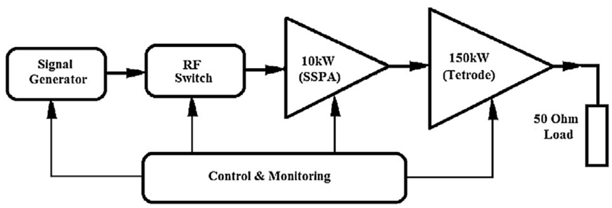

Fig. 2. Equivalent electrical layout.

Table 1
Electrical Characteristics of Tetrode.

Absolute Maximum Ratings	
DC Anode Voltage	22 kVdc
DC Screen Grid Voltage	2.5 kVdc
DC Grid Voltage	−1.5 kVdc
DC Anode Current	20 A
Anode dissipation	150 kW
Screen Grid dissipation	1750 W
Control Grid dissipation	500 W
Frequency of CW rating	110 MHz
Filament current for V_f = 15.5V	230 A
Inter electrode capacitances	
Cin	175 pF
Cout	60 pF
Cpk	0.35 pF

2. Operating parameters

A CPI make tetrode (4CW150000E) is selected to produce output power of 150 kW in the desired frequency range. The main electrical characteristics for grounded grid operation of the selected tetrode are shown in Table 1. Tetrode will be mounted vertically in the cavity. Typical grounded cathode configuration of the amplifiers requires neutralization to eliminate tendencies to oscillate. Therefore tetrode will be configured in grounded grid to provide electrostatic shielding between input and output, which will reduce the tendency of self-oscillation of the amplifier. An interlock system will be implemented to protect overall amplifier system from the unexpected faults and to provide safe operation.

2.1. Operational parameters

The amplifier is designed to operate in class B. Load line is drawn in between maximum plate voltage to be applied on plate and crossing point of minimum plate voltage swing to the peak cathode current for the operational conditions as shown in Fig. 3. The operating parameters are estimated using Chaffee method [3,4] which calculates anode, screen and control grid currents. The calculations are carried out to fit the operational parameters within the safe margins of maximum specified electrical parameters of the tetrode [5,7]. The operating parameters as shown in Table 2 are used to determine the operating parameters of the amplifier.

Table 2
Estimated operational parameters.

Output Power	150 kW
Input & Output Impedance	50 Ω
Anode voltage	14 kVdc
Anode Current	17.5 A
Screen Grid Voltage	1500 Vdc
Screen Grid Current	0.5 A
Control Grid Voltage	−370 Vdc
Control Grid Current	0.2 A
Anode dissipation	93.4 kW
Gain	13.4 dB
Efficiency	62%
Input Impedance	16.25 Ω
Output Impedance	400 Ω

3. Circuit description

At high power lumped components are not practical due to low impedance and high power density requirements [6]. Therefore, a co-axial structure for required cavities is always preferable, which also minimize the expected radiation losses. The amplifier mainly consists of input and output tunable coaxial cavities to cover the desired frequency range with tuning mechanism. The function of coaxial cavities is to provide appropriate frequency tuning and impedance transformation at the desired frequency within the range. It provides low spurious, losses and natural EMI shielding. The input and output cavities will be connected through 3-1/8" & 6-1/8" coaxial transmission lines respectively.

3.1. Input cavity

Input cavity mainly consists two co-axial copper cylinders extended from the tube terminals. Basically it is a coaxial 'T' having different characteristic impedances to connect tube at one port with fixed length (L1) & RF input on the second port with adjustable length (L3). Third port is also a variable length transmission line stubs for frequency tuning and to feed filament & air cooling. Input impedance matching is accomplished by using an adjustable length of coaxial line (L3) and a variable capacitor in parallel from 16.25 Ω to 50 Ω. There will be another conductor inside the cavity extend the filament terminal of the tetrode to connect the filament power supply. The outer most is the extension of the grid terminal, which is at rf ground and provide the electrostatic shielding for input. In the annular space of grid and cathode cylinders a short is put for the tuning of input circuit. An extension of cathode and grid tubes is made at 90° to form the input, where driver's output will be connected. The input cavity and its electrical equivalent circuit of the structure are shown in Fig. 4. The section of length L2 acts as a cathode stub. The section of L3 is a phase shifter and C_T is the tuning capacitor to tune out the resulting reactance at the input. Adequate spacing between the conductors will be kept to handle the drive power and to provide the required airflow for the base cooling.

Since tetrode has tendency to oscillate, damping material will be put between the annular spaces of both the grids to suppress unwanted oscillations.

3.2. Simulated results of the input cavity

RF simulation software RFsim99, linear S-parameter based circuit simulator, is utilised for simulation of input cavity. Simulation model is shown in Fig. 5 and results are shown in Figs. 6 and 7. The dimensions and value of capacitance needed to cover complete frequency range are shown in Table 3.

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