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Design of a 500 kW CW water load at 3.7 GHz for the LHCD system of SST-1 tokamak

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HIGHLIGHTS

- Design of a 500 kW CW Water Load for LHCD System at 3.7 GHz.
- Load design is carried out considering various multiple physics aspects.
- Coupled RF, Thermal, CFD and Mechanical Simulation.
- These loads would replace the existing 250 kW CW loads thus upgrading system capacity once the loads are fabricated and tested.

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ABSTRACT

The LHCD (Lower Hybrid Current Drive) system of the SST-1 Tokamak is commissioned for maintaining the plasma current for prolonged periods. The system relies on 4 Klystrons (TH-2103D) to deliver 500 kW CW power each at 3.7 GHz to maintain plasma discharge. High power microwave absorbers/dummy loads are required to condition the klystrons at high CW power level and to protect them against reflection. This paper presents a design of a novel and indigenous high power microwave dummy load using water as an absorber. The designed load was analyzed by considering various RF, thermal and mechanical aspects and is 300 mm in length. It provides excellent matching with an evaluated value of S_{11} of −38 dB and VSWR of 1.02:1. Simulation results show that it can absorb almost 99.99% of incident power.

1. Introduction

The LHCD system is commissioned on the SST-1 tokamak [1] at the Institute for Plasma Research, Gandhinagar to prolong the plasma discharge upto longer periods. The system relies on 4 klystrons (TH-2103 D) which are capable to provide a total power of 2 MW CW at 3.7 GHz ± 5 MHz through a grill antenna to the tokamak via an array of waveguides. The LHCD System is depicted in Fig. 1.

As the plasma impedance constantly changes, the reflection arising from the antenna travels back to the klystron which may hamper its operation. A scheme to protect the klystron is depicted in Fig. 2. A circulator, which allows only unidirectional wave propagation, is deployed such that the input power (F_1) from the klystron travels towards the tokamak (system) but any reflected power (R_1) is routed away from the klystron towards a dummy load/absorber (F_3). This load will absorb a major portion of the reflected power. Any power reflected from the load (R_2) will be transmitted via the circulator to another low power load (F_4) which will absorb most of it. The remaining reflected wave which would travel towards the klystron (R_3) will be effectively 50–60 dB less than R_1. In this way the klystron is protected from reflection.

The dummy loads which are presently deployed are rated at 250 kW CW. To operate the system at its maximum capacity, a dummy load with a rating of 500 kW CW is required. The objective of this paper is to present the design and simulation results of dummy load rated at 500 kW CW at 3.7 GHz.

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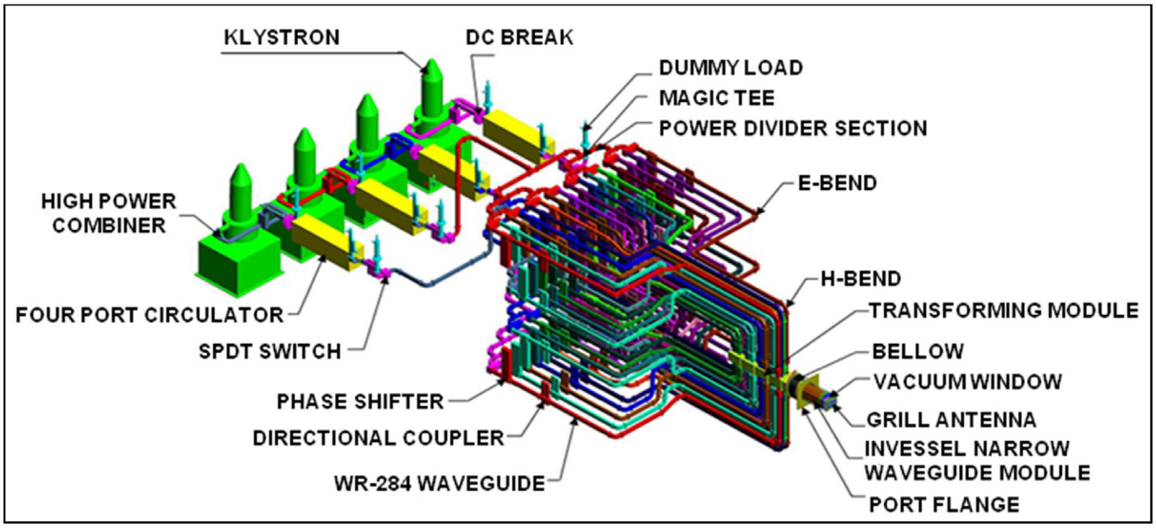

Fig. 1. Schematic of the Lower Hybrid Current Drive (LHCD) system.

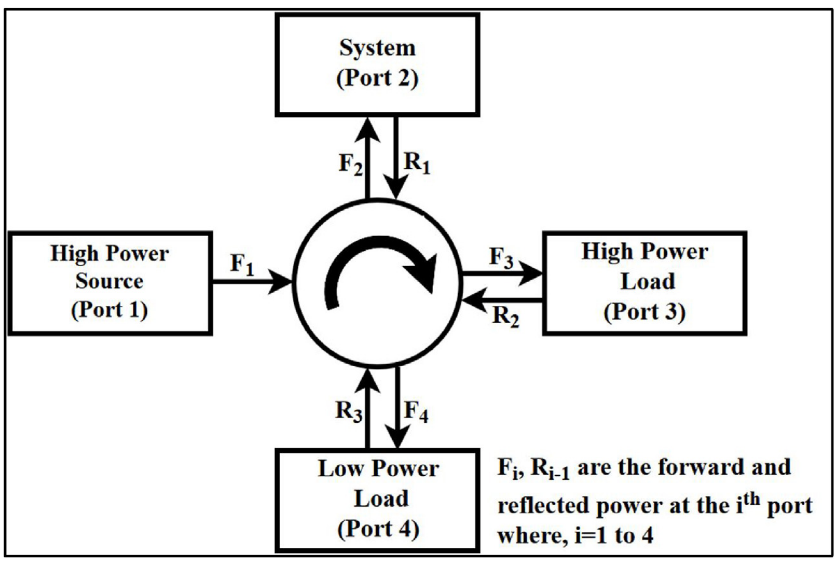

Fig. 2. Scheme to protect the klystron using circulator.

Such dummy loads have been developed and deployed in some countries engaged in fusion research [2–4]. Almost all of them rely on using water as an absorber due to its excellent capacity for microwave absorption at S band (3–5 GHz). The use of water also helps in effective and easy cooling of the load. The remainder of the paper is organized as follows.

Section II presents a brief overview of the loss mechanism of microwave in water, section III presents the specifications, detailed design and the multiphysics modelling of the water load while section IV presents the RF, Thermal and Stress results of the water load. section V concludes the paper.

2. Mechanism of loss in water

The complex relative permittivity of a material describes its dielectric property which influences the attenuation of the wave while propagating through it. The complex relative permittivity of a material can be expressed as,

$$\varepsilon = \varepsilon' - j\varepsilon'' \tag{1}$$

The real part of it represents the energy stored in dielectric and the imaginary part relates to the energy absorbed in the dielectric. Although different mechanisms exist which contribute to the dielectric loss such as polar, atomic, electronic and Maxwell-Wagner responses [5,6], the prime factor contributing to attenuation in water at RF and microwave frequencies are ionic conduction and dipole rotation [7]. Ionic conduction plays a major role at frequencies lower than 200 MHz while the dipole rotation primarily causes loss at our desired frequency (3.7 GHz). As the contribution of ionic conduction induced loss is marginal as compared to the dipole rotation induced losses in the GHz range [5], it is decided to use demineralised and deionised (DMDI) water in the proposed design. This would also prevent the blockage of cooling pipes and fittings. A lot of data is available on the loss exhibited by water at different frequencies and temperature and an excellent reference is [5,8]. A common expression for the complex relative permittivity of water found in them is given by Eq. (2)

$$\varepsilon = 5.62 + \frac{74.59}{1 + \frac{jf}{17}} \tag{2}$$

where, f is the frequency in GHz.