Design of RF Systems for the RTD Mission VASIMR[*]

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Abstract. The first flight test of the variable specific impulse magnetoplasma rocket (VASIMR) is tentatively scheduled for the Radiation and Technology Demonstration (RTD) in 2003. This mission to map the radiation environment out to several earth radii will employ both a Hall thruster and a VASIMR during its six months duration, beginning from low earth orbit. The mission will be powered by a solar array providing 12 kW of direct current electricity at 50 V. The VASIMR utilizes radiofrequency (RF) power both to generate a high-density plasma in a helicon source and to accelerate the plasma ions to high velocity by ion cyclotron resonance heating (ICRH). The VASIMR concept is being developed by the National Aeronautics and Space Administration (NASA) in collaboration with national laboratories and universities. Prototype plasma sources, RF amplifiers, and antennas are being developed in the experimental facilities of the Advanced Space Propulsion Laboratory (ASPL).

INTRODUCTION

Advanced rockets featuring high specific impulse, or exhaust velocity greater than 10^4 m/s, are required for fuel-efficient interplanetary manned missions and to reduce the flight duration. The VASIMR concept (1) offers the possibility of varying the specific impulse as needed to minimize the flight time. The VASIMR concept uses separate RF systems to ionize the propellant gas and to accelerate the ions to exhaust velocity.

NASA is planning a mission, known as the Radiation and Technology Demonstration, to conduct an environmental survey of the Van Allen radiation belts using both a 10-kW VASIMR and a 10-kW xenon Hall thruster. The RTD spacecraft will be deployed from the Space Shuttle and spiral out to 5 earth radii, releasing micro-satellites at regular intervals during the six months duration of the mission.

The experimental facility at ASPL (2) has been reconfigured to provide a magnetic geometry approximating that envisioned for the RTD rocket, using existing copper coils. This modified configuration, as shown in Fig. 1, is capable of steady-state

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operation at comparable magnetic field levels, allowing the testing of full-scale hardware for the RTD mission, shown in Fig. 2. The propellant gas, either hydrogen or helium, is injected on the axis at one end of the system. The gas is ionized by a partial-turn helical antenna launching a helicon wave. The low temperature plasma flows along field lines where it is heated by RF waves at the ion cyclotron resonance. The plasma continues into the nozzle where the perpendicular energy of the ions is converted into parallel motion. As the magnetic field becomes weaker in the exhaust region, the ion magnetic moment is no longer conserved and the ions break away from the field lines.

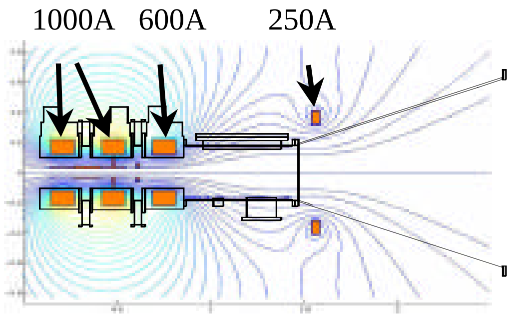

Figure 1. Three magnet ASPL configuration for RTD-like magnetic field geometry.

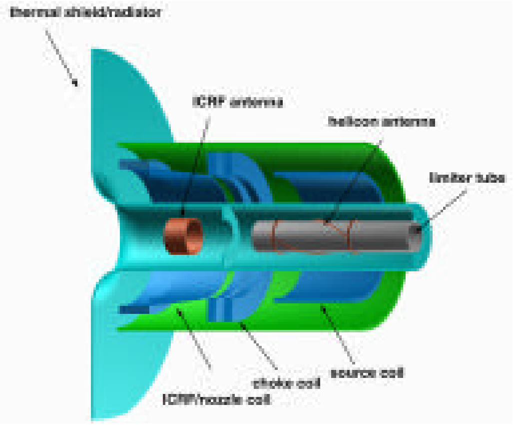

Figure 2. Artist's conception of the VASIMR for the RTD mission.

RF AMPLIFIERS

RF power for the helicon plasma source and the ICRH antenna will be generated by ten 1-kW solid-state amplifier modules. Each module uses two 600-W Motorola MRF-154 transistors. The split of power between the helicon and ICRH on the RTD rocket will be determined from the experiment at ASPL. Cooling of the amplifiers will be by a loop heat pipe.

Prototype amplifiers are based on a commercial kit (3). The commercial design is very broadband – operating over the range of 2–50 MHz – and has an output impedance of 50 Ω. To maximize efficiency, the bandwidth can be narrowed. The output impedance will be lowered to a few ohms in order to reduce the requirements for the matching network.

A photograph of the first prototype module is shown in Fig. 3. The unit is compact, measuring 10 cm × 18 cm × 2 cm. A second-generation cold plate reduces the total mass to under 1 kg. This module has been used to run the helicon source at ASPL, and will be used for thermal and longevity tests just beginning. It has been run successfully at an output power of 1 kW at 13.56 MHz for more than 1 hour. The large blocks of ferrite in the input and output transformers will be eliminated for the flight units. Since both the helicon and ICRH antennas are phased arrays, only two modules will need to have their outputs combined. Phasing is accomplished at the exciter level.

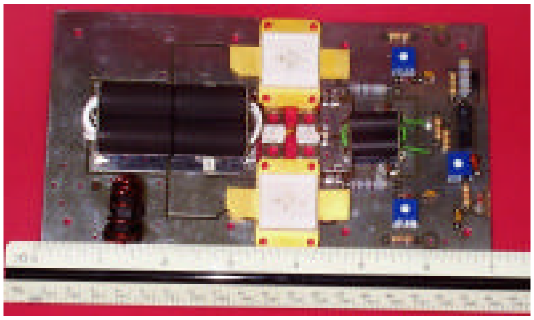

Figure 3. Prototype 1-kW HF-band RF amplifier module using 600-W transistors.

HELICON PLASMA SOURCES

A partial-turn helix helicon antenna has been operated in the system at ASPL. Figure 4 shows a discharge in helium. The parameters have been determined for operation in both He and Ar. Operation with H_2 will be conducted in the near future. The radial profile of density is shown in Fig. 5 for He operation. The source is normally operated at 13.56 MHz. Magnetic field strength and shape have been varied as well as gas flow rate. The direction of the magnetic field has been reversed with best results when the left-hand polarization is directed away from the exhaust end.

The antenna is water cooled for steady-state operation. For the RTD mission the antenna will be integrated as a loop heat pipe.

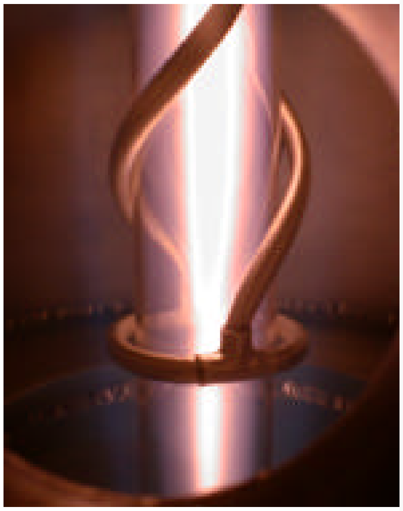

Figure 4. Steady-state helicon discharge in helium on the ASPL experiment.

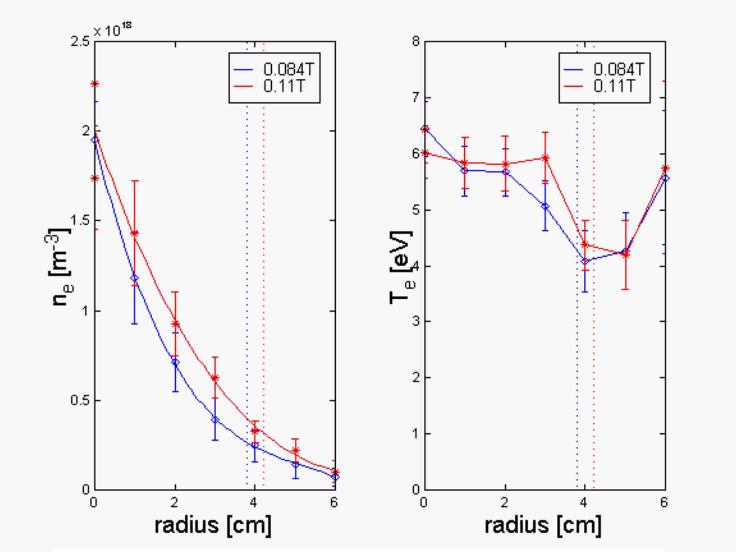

Figure 5. Profiles of density and temperature downstream of the helicon source for a helium plasma at two different values of magnetic field at the source.

ICRH SECTION

The ions passing through the magnetic mirror are heated at the fundamental ion cyclotron resonance just downstream of the ICRH antenna. For the RTD mission a quadrupole antenna is being designed, shown schematically in Fig. 6. Initial ICRH experiments at ASPL will be conducted using a pair of phased dual half-turn antennas at 3 MHz. Modeling with the EMIR code (4) shows that the ions can be heated to at least 100 eV in a single pass through the resonance; see Fig. 7.

The fields generated by the EMIR code are incorporated in a Monte-Carlo simulation of particle trajectories to optimize the exhaust efficiency (5). As the ions move toward the exhaust nozzle, the magnetic field decreases, and the perpendicular energy imparted by the ICRH is converted to parallel motion at the nozzle exit.

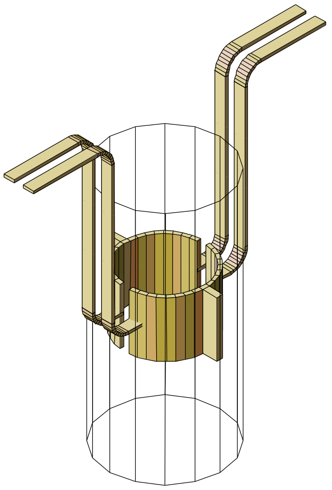

Figure 6. Quadrupole ICRH antenna for the RTD VASIMR.

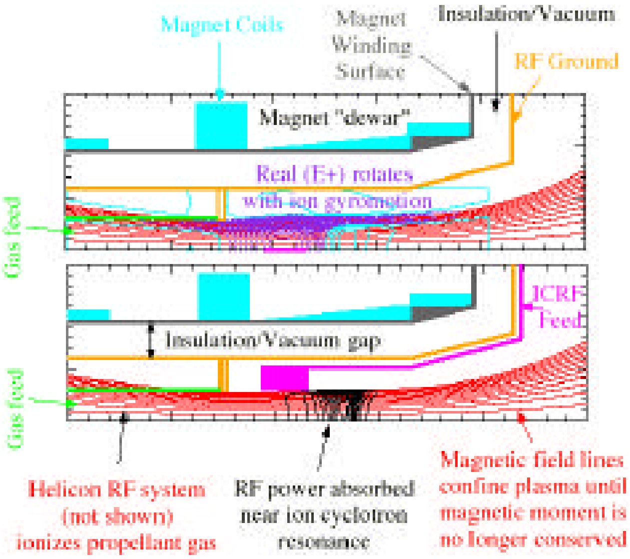

Figure 7. Electric field and power absorption generated by the quadrupole antenna the RTD VASIMR.

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