Aerospace Europe Conference 2023
Joint 10th EUCASS – 9th CEAS Conference

Abstract #XXX *(to be filled by the organizers)*
Preferred Topics: TESTING
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Type: Oral
Status of corresponding author: Student
For student corresponding author: student member of one of the following:

Title

Experimental measurements of radio signal attenuation and Faraday rotation due to electron number density in a plasma flow

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Abstract

Spacecraft entering in planetary atmospheres at hypersonic velocities generate shock waves ahead of the vehicle and consequent extreme aerodynamic heating. The high post-shock temperatures dissociate and ionize the gas creating a plasma layer that surrounds the spacecraft. High ionization degrees affect the propagation of the electromagnetic waves emitted by the on-board antennas, causing attenuation, polarization rotation and refraction (i.e. trajectory bending of the radio waves. Extreme ionization levels lead, ultimately, to communications blackout. In an un-magnetized plasma, the blackout occurs when the characteristic frequency of the plasma layer around the vehicle exceeds the radio frequency used for communications.

The Horizon 2020 MEESST (Magnetohydrodynamic Enhanced Entry System for Space Transportation) project aims at designing and testing a proof-of-concept magnetic shielding device for mitigation of radio blackout during space entry. As part of the project, this work investigates the effects of an ionized medium on the propagation of the radio signal through the plasma flow in a plasma wind tunnel facility. The experimental setup consists of two highly directive (beamwidth of 4.2°) circularly polarized horn lens antennas with a waveguide orthomode transducer, operating at Ka-band (between 33 and 40 GHz), connected to a Vector Network Analyzer (VNA). Each antenna is placed on opposite windows of the Plasmatron chamber and aligned perpendicularly to the jet axis. The narrow beamwidth of the emitted signal allows concentrating the transmitted power within the frame of the opposite window, hence minimizing the reflections on the metallic walls of the chamber. This hypothesis is confirmed by the good agreement between the magnitude of the measured signal without plasma and the theoretical link budget.

The scattering parameters measured experimentally with the VNA allow estimating the signal attenuation and the Faraday rotation due to the plasma. The theoretical estimation of the later depends on the frequency of the radio wave, the magnetic field strength, and the electron number density of the plasma. The magnetic field is estimated using analytical expressions for the magnetic field of a series of circular current loops combined with the Earth's magnetic field and compared to numerical simulations using an in-house inductively coupled plasma magnetohydrodynamics solver (ICP) for simulating the plasma flow field. The characterization of the electron number densities on the flow is conducted using high resolution optical emission spectroscopy, based on the broadening of the Balmer β transition of the atomic hydrogen line at 486.1 nm. These experimental measurements are compared to numerical estimations considering local thermodynamic equilibrium and to ICP simulations. Ultimately, these measurements also allow correlating the electron number densities with the signal attenuation, and to characterize the plasma flow.