Paper ID: 99499
student

IAF HUMAN SPACEFLIGHT SYMPOSIUM (B3)
Interactive Presentations - IAF HUMAN SPACEFLIGHT SYMPOSIUM (IP)

Author: Mr. Ashwin Rajkumar
University of Southern California, United States

DEVELOPMENT OF A UNIFIED ONE-DIMENSIONAL ELECTROSTATIC SHEATH FOR COMMUNICATION BLACKOUT MITIGATION

Abstract

With the exponential growth of human spaceflight missions, communication blackouts have become an increasingly critical challenge. This occurs when a spacecraft enters through a dense planetary atmosphere, resulting in the formation of a plasma layer around the vehicle's leading edge. The formation of this plasma layer is primarily driven by the ionization of ambient air, induced by the bow shock and frictional heating at the spacecraft's forebody. During this ionization phase, electrons are stripped from the neutral gas, generating a plasma composed of free electrons and positively charged ions. This layer attenuates electromagnetic (EM) waves due to its plasma frequency (w_p), which is dependent on the density of free electrons (n_e). When an EM wave encounters a plasma, if its frequency is lower than the w_p, the wave cannot propagate and is instead reflected. Vital signals often operate below this threshold, and are effectively blocked, resulting in a communication blackout; a fundamental challenge for human spaceflight. To address this challenge, a unified one-dimensional (1D) electrostatic sheath (ES) was explored to reduce the n_e, creating an opening through the plasma layer for signal propagation. A key aspect of this approach is understanding the behavior of a 1D ES, which is governed by the Child-Langmuir Law, an estimation for sheath sizes in steady-state conditions. However, prior research showed that under the 1D assumption achieving a 2 cm ES required 7 kV at a plasma number density of $10^{18}\,m^{-3}$, posing challenges such as cathode breakdowns due to a high E/N ratio, and arcing between electrodes which occur when the electric field exceeds the dielectric breakdown strength of the medium. These constraints informed design considerations, leading to the implementation of a magnetic field near the cathode to confine the electrons in tighter orbits, reducing the breakdown risk. Additionally, a parallelly unified 1D ES system was investigated to distribute the high voltage across multiple systems. Paschen's Law then further optimized the apparatus by finding the minimum distance at which breakdown voltage occurs for each electrode and ES system effectively reducing arcing. Initial experimental validation was performed using radio waves, and results of signal propagation and required voltage were scaled to justify feasibility for GPS, Data Telemetry, and VHF. This research builds upon previous studies, by demonstrating the application and scalability of a unified 1D ES system to enhance mission safety and mitigate communication blackouts, thus advancing human spaceflight.