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ADVANCED THERMAL MANAGEMENT: PRE-DESIGN OF A MECHANICALLY PUMPED FLUID LOOP FOR WIRELESS POWER TRANSMISSION SATELLITES

Abstract

The increasing power requirements of space-based systems, particularly those utilizing Wireless Power Transmission (WPT) via laser, present significant thermal management challenges. Due to the limited efficiency of laser diodes, approximately 50% of the transmitted energy is converted into waste heat, necessitating an effective heat dissipation system. This study focuses on the preliminary design and trade-off analysis of a Mechanically Pumped Fluid Loop (MPFL) for thermal control in high-power satellite applications. A key application investigated is the wireless recharging of a lunar base, addressing the critical challenge of ensuring reliable and continuous energy supply for extended lunar missions, particularly during eclipse periods when solar power is unavailable.

The research methodology employed in this study adheres strictly to the European Cooperation for Space Standardization (ECSS) recommended approach. This involves the systematic definition of system requirements, operational modes and various mission scenarios, with the objective of identifying the most critical operating conditions for both hot and cold cases.

A Thermal Network Method (TNM) is implemented, modelling key satellite subsystems—including the laser diode array, battery pack, solar panels, and avionics—within an MATLAB-Simulink environment. The analysis is complemented by simplified 3D models, which also facilitate the optimization of the laser diode arrangement for enhanced thermal performance.

A trade-off analysis is conducted between different thermal architectures, including single-phase and two-phase mechanically pumped fluid loops (MPFL), loop heat pipes, and other solutions, to identify the most effective heat dissipation strategy. The selected architecture is then preliminarily dimensioned, thus defining the TRLs of its components and overall dimensions and volumes. The radiative panels are also estimated through an iterative process that ensures that all satellite components remain within their operating temperature ranges. In order to reduce the strain on the thermal control system, the most dissipative components are reconfigured and repositioned within the satellite.

The findings of this study provide a foundation for the development of advanced thermal control systems for future spacecraft featuring high power consumption and significant heat dissipation requirements. This research contributes to the ongoing advancement of space-based WPT technologies, offering insights into scalable and efficient thermal management solutions for next-generation satellites.