Power Hibernation for Low-Cost Solar Powered Lunar Missions.

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Because the surface of the Moon drops to cryogenic temperatures, no solar-powered lunar spacecraft have reliably operated beyond a single lunar day. Passive thermal control cannot keep a spacecraft sufficiently warm for the 354-hour lunar night, and active thermal control requires a dramatic increase in battery mass at the expense of payload mass. Extreme conditions seen on the lunar surface suggest a radioisotope solution is ideal, but mass, cost, and schedule are inconsistent with low-cost frequent flight intent of the commercial lunar payload services (CLPS) program.

To solve the issue of lunar night survivability without radioisotope sources of power and heat, a lunar power hibernation approach is being developed at the Glenn Research Center, which exploits the ability of common 18650 Lithium-ion cells to passively survive cryogenic freeze-thaw cycles, recovering without apparent performance degradation [1]. A key aspect of this hibernation approach is the use of cryogenically-operable electronics that safely manage the restoration of the battery thermal environment at lunar dawn.

A spacecraft utilizing this strategy will operate into the lunar night on batteries until the state of charge or spacecraft temperature reaches a predetermined threshold. At this point, systems are shut down and the battery is isolated from the main bus to prevent charge or discharge during the freezing and thawing transitions. The system remains passive until lunar dawn, where temperatures can reach as low as 50 K. All electronics must be tolerant to these conditions. When the solar arrays are finally illuminated at lunar dawn, the main bus power electronics will initiate a “cold start” and begin regulating array power. The main bus electronics must be designed to operate at cryogenic temperatures [2].

Array power is used to warm the battery and passive electronics back to operational temperatures. Once batteries are returned to normal temperatures, diagnostics and pre-charging is performed, as needed, and the battery is reconnected. The overall spacecraft system reboots and returns to nominal operations until lunar night returns.

To assure that we can develop batteries suited for many hibernation freeze/thaw cycles, Space Technology Mission Directorate’s Space Technology Research Grant Program (STRG) [3] has selected two universities to investigate and thoroughly characterize of the Li-ion cell through the freeze-thaw process. The research investigates degradation mechanisms, and identify potential diagnostic techniques.

STMD STRG is also funding an investigation of Gallium-Nitride semiconductors for cryogenic power applications. This work includes physics-informed modeling that considers carrier mobility, and quantum effects that govern semiconductor performance at cryogenic temperatures. These models can enable engineers to develop accurate cryogenic simulation models that assist in the design of power controls that will be stable over the 50k to 400K temperature range.

Meanwhile, Glenn is performing cryogenic testing of batteries and electronics, establishing design guidelines for power applications in extreme cold lunar environment, and potentially developing a hibernation technology demonstrator.

The hibernation approach will enable low-cost lunar robotic missions to extend their operating lifetime to many months while minimizing development costs and impact on payload capacity. The need for cryogenically operable electronics is restricted to only main bus power and battery controls, as the majority of systems simply need to passively tolerate cryogenic temperatures. This allows developers to continue to exploit the cost savings of legacy hardware with minimum modification. For these reasons, lunar power hibernation is a viable near-term solution for lunar night survivability for solar powered commercial landers.

References

[1] R. Oeftering, W. Bennett, M. Gonzalez and N. Uguccini, "Power Architecture for Hibernation and Dawn Mode Operations," in 38th Space Power Workshop, 2021.
[2] R. Oeftering, N Uguccini, L. Tian, “An Assessment of Cryogenic Analog Electronics for the Lunar Environment”, 39th Space Power Workshop 2022.
[3] NASA Research Announcement, SpaceTech-REDDI-2022, Early Career Faculty Appendix: Topic 2: Hibernation and Recovery of Solar-Powered Systems for Lunar Missions, Feb 2022