Development of the TEthered Mechanism for Persistent Energy Storage and Transmission (TEMPEST) System for the Watts on the Moon Challenge. T.Wavrunek[1] and P. van Susante[2], Michigan Technological University, 1400 Townsend Dr., Houghton, MI 49931, United States, [1]tawavrun@mtu.edu, [2]pjvansus@mtu.edu

Introduction: NASA's return to the moon as part of the Artemis program will require the development of infrastructure that is capable of operating on the harsh lunar surface. One of the most important capabilities needed for a sustained human presence and for large scale in-situ resource utilization actives is the long-range transmission and storage of power. Transmission of this power must occur at the kilowatt level over kilometers of separation between nodes, and energy storage must be sufficient to power operations through the lunar night.

To address this technology gap, NASA began the Watts on the Moon Challenge in Fall of 2020. This challenge tasked teams with finding solutions to these energy distribution, power management, storage, and thermal technology challenges over multiple project phases[1].

With prior experience in lunar power transfer from the T-Rex submission to the 2020 BIG Idea Challenge [2][3], the Planetary Surface Technology Development Lab (PSTDL) at Michigan Technological University developed a solution. The TEthered Mechanism for Persistent Energy Storage and Transmission (TEMPEST) is a high-efficiency power solution that takes advantage of the extreme environment of Lunar Permanently Shaded Regions (PSRs). Using interchangeable tethers, lithium ion-energy storage capacity, and a passive thermal management system, TEMPEST is designed to enable operations within a wide range of mission scenarios.

Operation: As part of the challenge, TEMPEST receives intermediate power generation, simulating a shortened day/night cycle. The power is stepped up then transmitted to an energy storage system, and power is supplied to a load simulating operation of a water processing facility. The load profile consists of two 24-hour periods; six-hours where power is available from a generation source and 18-hours where energy must be provided to the load from energy stored within the system (Figure 1).

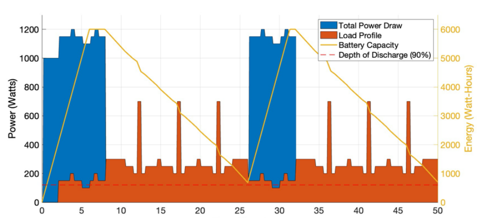

Figure 1. Load Cycle for the Watts on the Moon Challenge, overlaid with anticipated TEMPEST Battery Capacity

Challenge testing will occur within thermal vacuum (10E-3 Torr and liquid nitrogen cooled thermal shroud) and teams are judged on their ability to successfully complete the load profile while minimizing mass and maximizing efficiency.

The electrical subsystem of TEMPEST (Figure 2) was designed to minimize complexity while aiming to maximize the reliability of our power delivered. Commercial off the shelf parts are used where available for conversion.

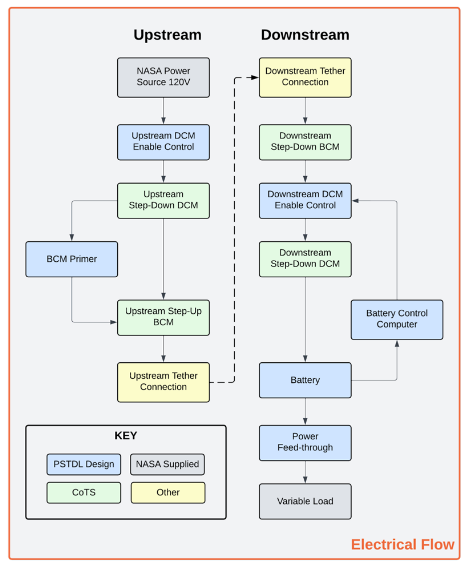

Figure 2. High-Level TEMPEST Electrical Flow Diagram

Key Testing: Key testing of subsystems was important to validating the effectiveness of TEMPEST as a full system.

Cryogenic Power Transfer. TEMPEST is designed to use two different tether materials, dependent on the ambient conditions. Within a PSR, temperatures commonly fall below 70K. This extreme cold enables the use of a superconducting tether. Superconductors such as Yttrium Barium Copper Oxide (YBCO) reach a state of zero electrical resistance when cooled below their transition temperatures (93K in the case of YBCO).

The PSTDL has shown that the YBCO tether design achieves superconducting in thermal vacuum conditions (Figure 3). High current testing of superconducting tethers is still ongoing at the PSTDL.

In regions where radiative temperatures do not facilitate superconducting, TEMPEST uses a flat aluminum tether. The geometry of the flat tether creates a greater radiative surface, cooling the tether further than a round geometry and reducing the effective resistivity due to temperature coefficient of aluminum's resistivity.

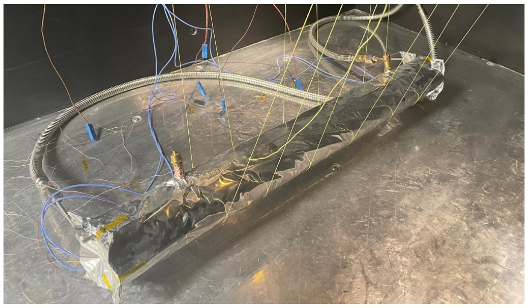

Figure 3. Secondary Thermal Shroud Used in Superconducting Power Feedthrough Test[4]

Battery Vacuum Qualification. TEMPEST's energy storage solution is a series of 9x 228Ah lithium iron phosphate (LFP) cells totaling at a capacity of 6566 Wh. LFP cells were chosen for use in TEMPEST due to their high safety, large temperature range, and low cost compared to other lithium-ion cell chemistries.

However, due to the lack of flight heritage of the LFP cells used on TEMPEST, the PSTDL has completed a series of vacuum tests to ensure safe operation of the battery pack during the challenge (Figure 4).

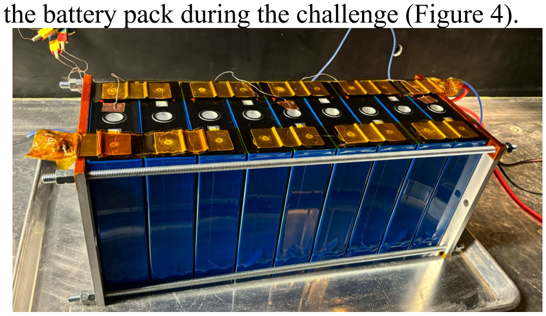

Figure 4. Image of TEMPEST 6566 Wh Battery Testing in Ambient Temperature Vacuum Conditions

Passive Thermal System. With the thermal environment being a major concern in the challenge, significant design was put into the thermal system for both the upstream and downstream TEMPEST modules. A reservoir of phase change material (PCM) actuates a thermal switch. The thermal switch isolates the electronics and the battery from the radiator when the switch temperature is below a certain temperature and heat must be conserved. During the charging period of the cycle, TEMPEST creates excess heat due to power conversion losses. Pulsating Heat Pipes (PHPs) are used conduct heat from the hot electronics to the PCM switch and the radiator (Figure 5).

Development of a thermal model of TEMPEST's thermal switch and pulsating heat pipes was validated through subsystem testing in thermal vacuum. Results of this testing were fed back into the model to better inform our thermal design parameters and size of the radiator.

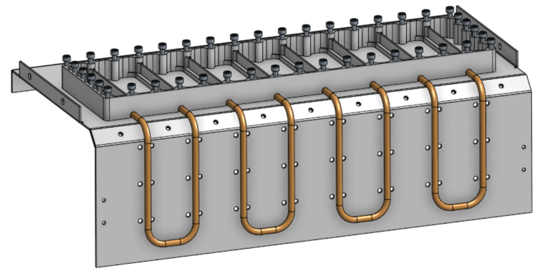

Figure 5. CAD Image of the Downstream TEMPEST Passive Thermal System

Conclusions: The TEMPEST system is designed to meet the requirements defined by the NASA Watts on the Moon Challenge. Leveraging the PSTDL's prior experience with lunar power transfer led to a system designed to perform optimally in a cold environment using a super-conducting tether. The passive thermal system conserves waste heat while maintaining battery temperatures, supporting the LFP battery cells and commercial off-the-shelf power converters to enable cold temperature operation while lowering system costs and reducing safety risks.

References:

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