

Compact Ultra Low Temperature Instrumentation for the Lunar Surface

P.E. Clark¹, S. Whitaker², G. Maki², K. Brown³, R. Cox⁴

¹Catholic University of America, ²ICs, ³Morehead State University, ⁴Flexure Engineering

Contact: Pamela.E.Clark@NASA.gov

Context

The single most important discovery in lunar science in the last decade is the confirmation of icy volatiles at the lunar poles. This discovery implies that volatiles are far more ubiquitous on most of the surfaces in the solar system, for which the lunar polar regions are an analogue, than previously assumed. Apparently, the solar system still has far more to reveal about its origin, history, and current state. This not only makes the Moon an exciting destination in its own right, but the Lunar polar regions a Rosetta Stone for cryogenic chemistry and physics throughout the solar system and beyond, and a testbed for technologies needed to support exploration of the entire solar system.

Purpose

Here, we discuss technologies needed to support such exploration of the lunar polar regions, their current state of and ongoing activities related to their development, particularly in regard to cold temperature electronics. A particular concern is operation under the colder and darker conditions at or near the lunar poles, particularly in the always or nearly always shadowed regions that can act as efficient cold traps for such volatiles.

How it Started

Two years ago, we began a multi-year effort to develop strategies and design concepts for ALSEP-like stand-alone lunar surface instrument packages with minimized mass/power requirements and without dependence on radioisotope-based batteries. We used a state of the art lunar environmental monitoring station (LEMS) that would be operational at all times at the poles for a minimum of five years. as our model. An initial conventional attempt to design an environmental monitoring package with a solar/battery based power system led to a package with a unacceptably large mass (500 kg) of which over half was battery mass. Our Phase 1 support allowed us to design a package with considerable reduction (5x to 100 kg) in the initial mass of such a package deployable near the poles (up to a few days of darkness once a year) by incorporating a) radiation hard, cold temperature electronics readily available but not routinely considered for deep space missions and b) innovative thermal balance strategies through use of multi-layer thin materials and gravity-assisted heat pipes.

Technology Challenges: Thermal, Mechanical, Mechanisms

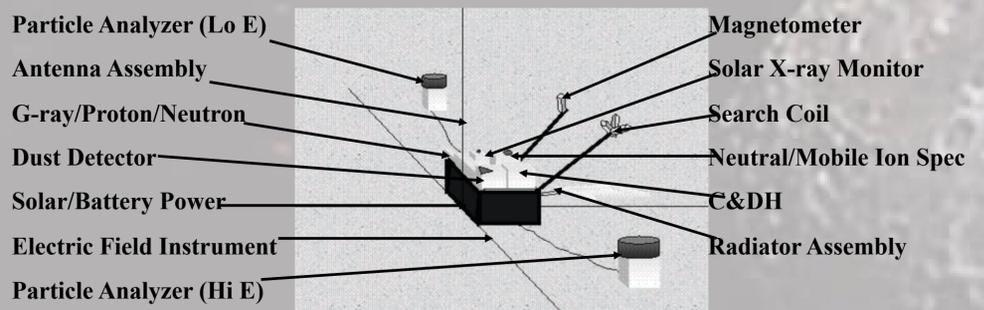
Thermal and mechanical design must provide a shield from extreme environmental conditions as well as deep space radiation on the lunar surface. Clark and coworkers developed a concept for a passively temperature controlled instrument package operating on a limited duty cycle using JWST G10 material as insulation, a radiator with latitude dependent alignment, and a gravity-assisted heat pipe to greatly reduce heat loss during lunar night. NASA recently developed polymer aerogel (no longer brittle) material would provide even better insulation with even less mass penalty and allow an expanded duty cycle. known. High temperature superconductors could also provide the basis for efficient mechanisms for applications where 'moving parts' are required to operate under cryogenic conditions where minimal power is available, as well as for magnetic shields to protect equipment or crew in deep space radiation environments. Such HTS-based concepts have been designed and tested.

Technology Need	Science	Robotic Precursor	Human Occupation
Thermal Design: State-of-the-art thermal design for cold, hot, and/or large temperature gradient surfaces, including phase change, insulating, multi-layered packaging and heat pipe technology, in order to reduce need for active heating or cooling while reducing mass and power requirements.	remote automated operation instrument packages deployed robotically or with human crew on planetary surfaces	remote automated operation instrument packages deployed robotically (monitor environment)	Long duration operation instrument packages deployed robotically or with human crew (monitor environment, ISRU)
ULT Batteries/Power Supplies: Energy storage devices capable of operating efficiently and surviving over wider range of, especially ultra-cold, temperatures, designed for smaller scale applications, including batteries and ultra capacitors	remote automated operation instrument packages deployed robotically or with human crew on planetary surfaces	remote automated operation instrument packages deployed robotically (monitor environment)	Long duration operation instrument packages deployed robotically or with human crew (monitor environment, ISRU)
ULT/ULP Electronics Ultra-low power/ultra-low temperature electronics for all subsystems 'system on a chip' capable to reduce power requirements and the need for heating	any instruments, tools, equipment requiring electronics	any instruments, tools, equipment requiring electronics	any instruments, tools, equipment requiring electronics
Solar Tech: More efficient radhard flexible, lightweight solar cell technology, alternative to expensive radioisotope based power	Any application utilizing solar energy	Any application utilizing solar energy	Any application utilizing solar energy
Development of currently low TRL instruments concepts capable of providing rapid comprehensive surface/subsurface analysis/ reconnaissance of samples in the field or lab with minimal sample preparation or consumables for extreme environment operation with minimal resources	Powered instruments and tools for robotic or human lab or field applications	Powered instruments and tools for robotic reconnaissance	Powered instruments and tools for EVA and IVA use
Sample/Surface interfaces including drills, probes, ports or attachments integrated with instruments to allow assessment of surface and subsurface with minimal mass, power and volume.	Powered instruments and tools for robotic or human lab or field	Powered instruments and tools for robotic application	Powered instruments and tools for robotic or human lab or field, ISRU
Solid and Particulate Sample containment and Handling State-of-the-art reversible, minimal mass collection and containment techniques for desirable samples and for removal of particulates from required clean surfaces. Automated sample preparation and handling equipment.	Any application requiring sample preparation, containment, or surface cleaning for analysis as well as dust mitigation	Any application requiring sample preparation, containment, or cleaning for reconnaissance as well as dust mitigation	Human physiology, facility monitoring, and dust mitigation applications, ISRU

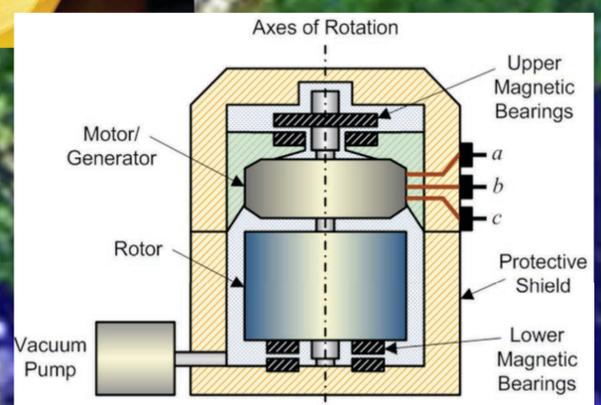
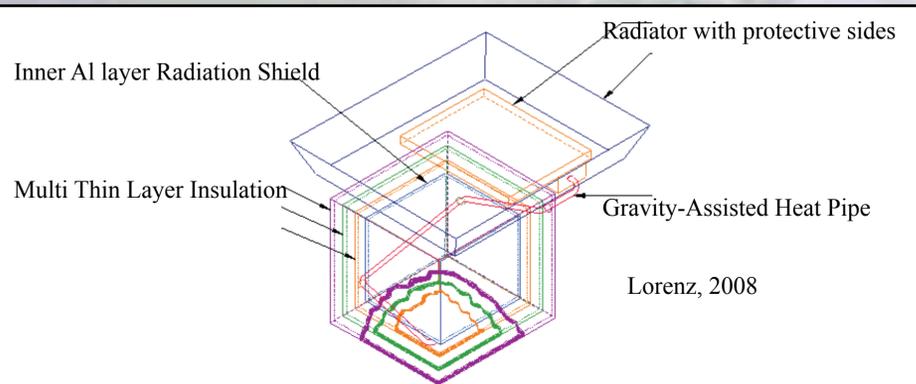
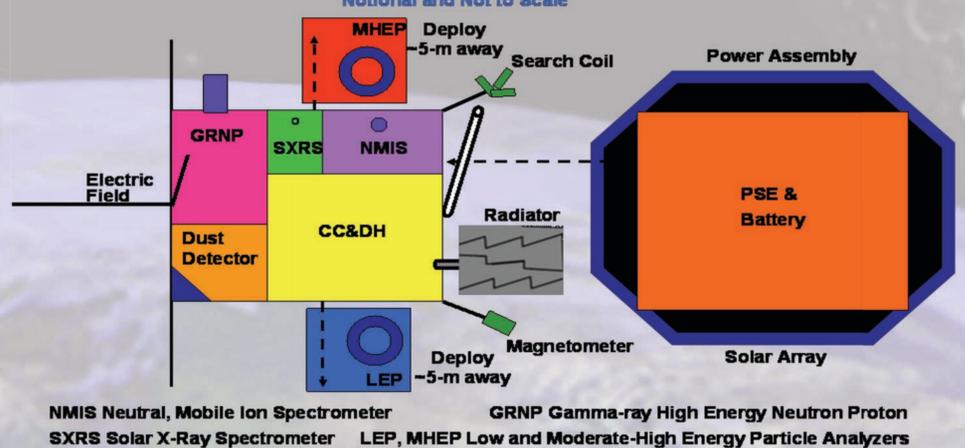
Reduction in mass and power for LEMS as new concepts were used

Design Regime	Conventional Electronics	Cold Electronics	New Packaging Concept
Operational Limit C	-10	-40	-40
Survival Limit C	-20	-50	-50
Battery Mass kg	240	120	30
Remaining Mass kg	260	260	70
Total Mass kg	500	380	100
Minimum Power W	50	30	10

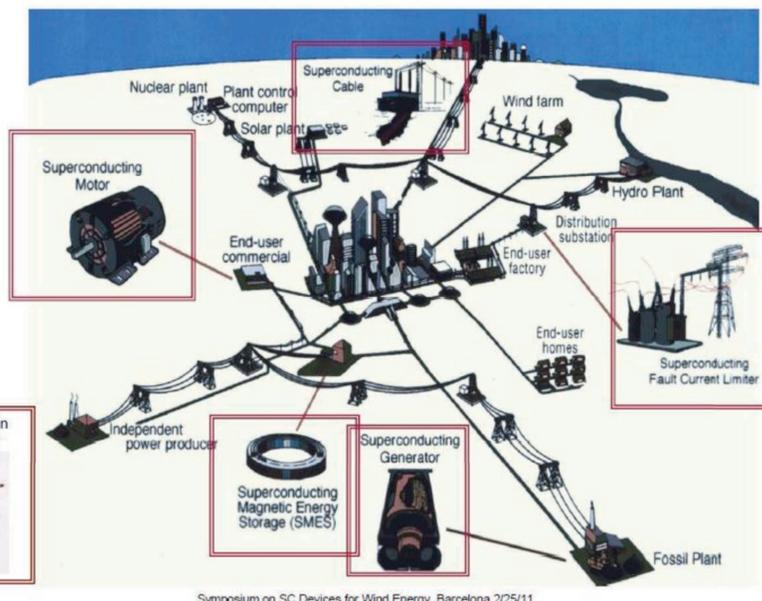
Present Automated Lunar Environmental Monitoring Station Concept



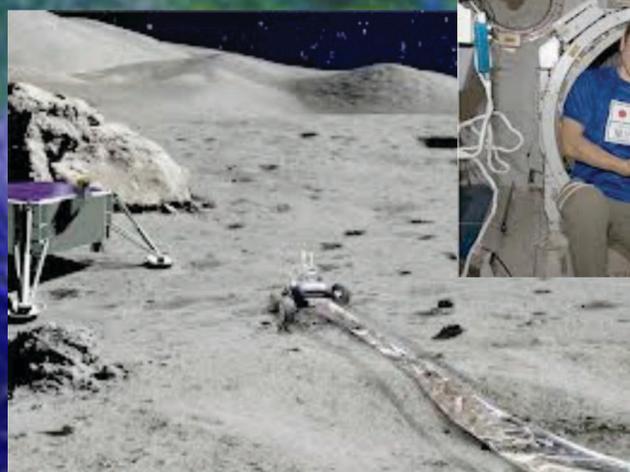
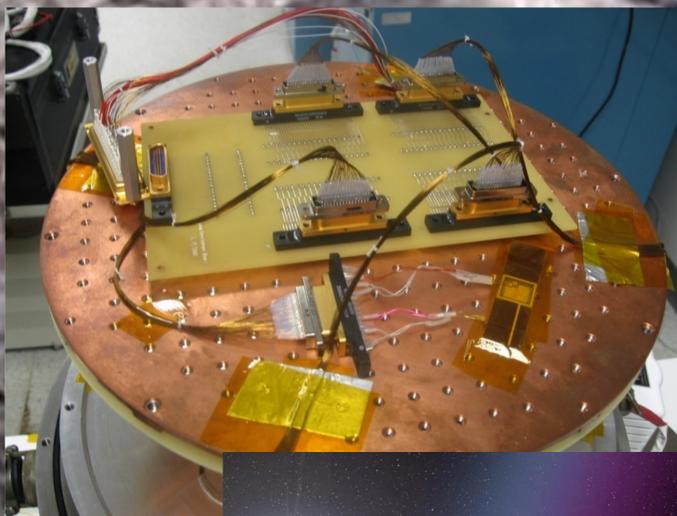
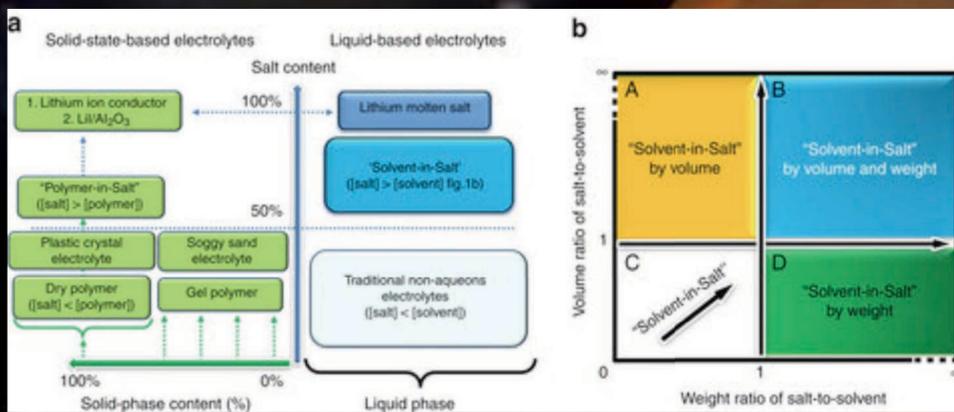
LEMS Assembly System Layout



Superconductors: improving the generation and delivery of power



Symposium on SC Devices for Wind Energy, Barcelona 2/25/11



Technology Challenges: Power

Designing power systems to operate at cold temperatures is especially challenging.

Hibernation has been proposed to provide limited duty cycle operation on the lunar surface.

Li battery technology has been undergoing systematic improvement at JPL through the use of electrolytes that can carry charge at far lower temperatures than conventional batteries. Indications are that Li-based battery technology will allow operation down to -100 degrees C within the next few years. Recently, solvent-in-salt electrolytes have been studied and shown to enhance charge/discharge and safety performance.

For operating at the extremely cold temperatures in the permanently shadowed areas on the Moon, down to 25K, we will need high temperature superconductor systems now under development by Selvamanickam, Masson, Beno, Meinke, and others. High Temperature Superconductor based systems for cooling, power generation, power transmission, energy storage and regulation (superconducting magnetic energy storage or flywheel) are currently being developed tested for the large-scale applications for efficient power generation, but we will require the same scales that are normally used in the laboratory. HTS-based technologies, although currently relatively low TRL, would provide optimal solutions for operating at cold temperatures.

Technology Challenges: Avionics, Electronics

Cold temperature analogue (Si Ge) [8] and digital (ULT, ULP) electronics that will currently operate at these 'cryo' temperatures far more efficiently and with lower noise than conventional electronics are available now, and awaiting an opportunity to be employed in the design of an entire package, which may need to be designed to operate at a lower voltage. ULT/ULP chips demonstrated orders of magnitude savings in power consumption and thermal tolerance (Maki and Yeh, 2003) on CULPRIT (CMOS Ultra-low Power Radiation Tolerant) flown on NASA ST5 (2006), similar high end channel coder and compression chips requested for use in MMS, GOES-R missions. Currently, CAMBR (Center for Advanced Microelectronics and Bio-molecular Research)/Idaho team with U. Michigan, completed rad-hard-by-design (RHBD) test chip for 90nm, as well as low-power cross-correlator chip capable of performing over 10,000 correlations simultaneously at 800 Mhz for ESTO (Instrument Incubator Program) instrument project (GEOSTAR) with JPL lead PI.

Recent development in low-power rad-hard electronics involves smaller CMOS feature sizes, currently down to 90nm and 65nm. At these sizes, the core voltage of chip in range of 1.0V, a 25:1 power reduction compared to earlier 5.0V components.

Though ULP likely more energy efficient (by factor of 4), requires access to fabrication process (e.g., change doping recipe) not as readily available. 90 or 65nm may offer alternative solution to ULP electronics.

Applications

We have proposed to target onboard avionics needs of deep space autonomous systems, including communications as well as command, control, and data handling, through development of a general purpose, radiation hardened by design (RHBD) processor that can also serve as a programmable controller for varied applications, as applied to a specific instantiation: LunarCube, the very low-mass, low-power, and low-cost yet capable standardized spacecraft bus concept that has enabled the highly successful CubeSat model for deep space operation. The current concept leverages the Morehead State CXBN mission 3U bus [12], capable of accommodating a single guest instrument, to be self- or human-deployed on the lunar surface.

The most challenging surface activities which we will ultimately address include measurement and curation of cryogenic samples, robotic rover operation at or near cold traps, combined in situ measurement techniques in lieu of sample handling techniques, and distributed, self-deploying astrophysical observatory networks, such as ROLSS.