

**LUNAR GEOPHYSICAL INSTRUMENT PACKAGE (LGIP) II – POWER AND PROBE DEVELOPMENT.** J. D. Weinberg<sup>1</sup>, B. Heshmatpour<sup>2</sup> and C. R. Neal<sup>3</sup>, <sup>1</sup>Ball Aerospace & Technologies Corp., PO Box 1062, Boulder, CO 80306-1062, jweinber@ball.com. <sup>2</sup>Teledyne Energy Systems, Inc., 10707 Gilroy Rd, Hunt Valley, MD 21031, ben.heshmatpour@teledyne.com. <sup>3</sup>Dept. of Civil Eng. & Geo. Sci., University of Notre Dame, Notre Dame, IN 46556, neal.1@nd.edu.

**Introduction:** As with the Apollo Lunar Science Experiment Packages (ALSEP), it is likely that the next Lunar geophysical network will be incrementally built up in a variety of locations, using a number of missions over a long period of time. This necessitates the use of a reliable, long-lived power supply, that will allow the initially deployed packages to still function when subsequent packages arrive on the lunar surface so that they can all operate as a network. Science goals also dictate that measurements be made over an extended period of time, and that Lunar Geophysical Instrument Packages (LGIPs) be deployed globally across the lunar surface in strategic locations so as to maximize science return and environmental characterization [1].

A Planetary Instrument Design and Development Program (PIDDP) has recently been awarded to develop an LGIP for use in a long lived Lunar geophysical network. System Engineering and development goals traditionally attempt to minimize cost and complexity by designing a single LGIP that can be fabricated multiple times and function at all desired locations and conditions with minimal or no modifications. The difficulty in making a “universal” package, however, lies in the large variability of deployment schemes, locations, operating environments etc. Some environments, such as radiation, are governed by statistical processes. Others, such as the dust environment are more constant or even manageable.

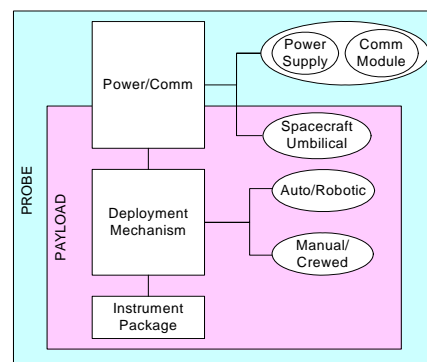
**Probe Design Considerations:** This poster examines key environmental and operational considerations for LGIP probe design, including temperature, deployment technique, communications scheme and power source. A preliminary architecture is outlined, and the use of commercially available small multi-watt radio isotope power supplies (RPS) is considered.

**Temperature.** Perhaps the most influential environmental design parameter for any Lunar surface hardware is temperature. The Moon has a wide variability of surface temperatures [2]. The combined spatial and temporal variability ranges from 40K in shadowed polar craters to nearly 400K at the solar illuminated equator. Even staying in one mid-latitude spot, the day-night temperature variation is on the order of 280K. However, at depths as shallow as 30 cm beneath the lunar regolith, Apollo probes found temperatures close to average (220 to 255 K), with almost no day-night variation ( $\sim \pm 3$  K).

A variety of temperature mitigation strategies are available including insulation, radiators and heat pipes, electric heaters, radioactive power waste heat or burrowing the entire package into the lunar regolith.

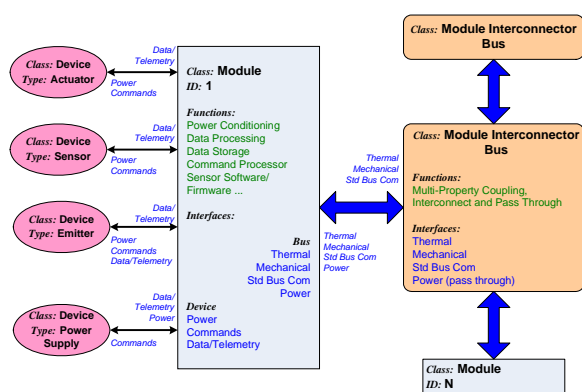
**Concept of Operations (ConOps):** The probe deployment technique, communications scheme and power source options all are largely dependent upon whether the LGIP will be used as a payload (attached to a robotic or crewed lander), or as a stand-alone probe (**Fig. 1**). If the package is merely an instrument suite, then power and communications can be provided by a host spacecraft, or via an umbilical to a landed crewed vehicle. In this case, the lifetime of the package is limited by the lifetime of the lander. If the package is designed as a stand-alone probe, it will require it's own power source and communication module.

Lunar far side probe deployments will require an orbital communications relay to exchange commands and telemetry with Earth. Near side probes can either use an orbital relay or direct to Earth (DTE) transmission. Other options include the use of a Lunar surface relay station or network. DTE probes may require more power and different antennae than those which rely upon a telecom relay.



**Figure 1 –LGIP ConOps Approach**

**Probe Architecture.** To allow for all operational possibilities using a single architectural solution, the LGIP can be designed with high modularity, so that the instrument package design can be separated from the deployment mechanism and power/comm module. The modules may then be joined together with standard, well-defined connections that provides a thermal, mechanical and electrical (power, commands and telemetry) interface. This also allows for separability of instrument modules from core probe functions, which



**Figure 2 – Sample LGIP architecture**

allows for “mixing and matching” of instruments in the payload, without disrupting the overall system architecture. The approach is similar to the object oriented philosophy of modeling, simulation and advanced software design. A sample architecture is outlined in **Figure 2**.

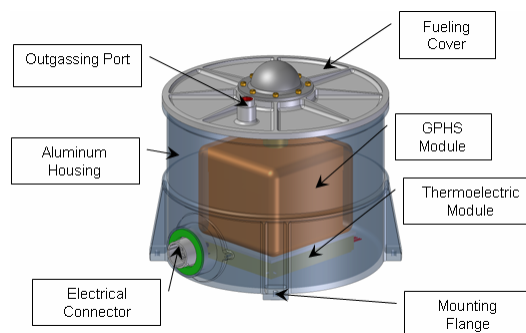
Each module acts as a standalone unit, providing data processing, storage, control circuits, command handling and power conditioning for all of the devices attached to it. Devices fall into one of four classes: actuator, sensor, emitter or power supply. Actuators include devices such as motors, gimbals, valves and deployment mechanisms. Examples of sensors include thermocouples, pressure sensors, magnetic detectors, CCDs, radiation detectors, etc. Emitters constitute anything that emits energy as it's primary function, such as heaters, RPS heat, RF transmitters and lasers. Power supplies can be any type of energy generator including solar arrays, batteries or radioactive power sources.

Modules are completely responsible for servicing their connected devices through custom interfaces specifically designed (or chosen) for each device. The modules are all assembled in a Module Interconnector Bus (MIB), which provides a standard data and power interface as well as a mechanical attachment and a thermal interface. MIB's may be connected to other MIB's or to other modules.

**Small Multi-Watt RPS Options:** Even with advancing battery technologies, it is unlikely that they will be able to provide the extended power needed for LGIP probe operations (i.e.  $\geq 6$  years) any time in the next several decades. Mass constraints, long mission duration, thermal cycling, and long intervals (up to 14 days or more) without sunlight make popular choices such as batteries, solar power and fuel cells unattractive and impractical. The use of radioactive power such as small multi-watt RPS units is an enabling technology for a long lived Lunar geophysical network.

This presentation looks at some of the options available for a multi-watt RPS for use in a LGIP probe. All design options have a high technology

readiness level (TRL) and are based upon heritage Teledyne hardware which has flown on past space missions. These designs are mature, multi-mission, highly reliable, and offer long life. The most promising option for LGIP is a design based upon a single General Purpose Heat Source (GPHS), as shown in **Figure 3**. Thermal and thermoelectric performances have been optimized and the resulting designs are all compliant with NASA guideline requirements for multi-watt RPS units for future space missions, including long life (7-14 yr), 40 G load tolerance, 1-20 We @ 5 VDC EOL



**Figure 3 – Multi-watt RPS design using a single full GPHS block**

and use of a single GPHS with existing fuel capsules [3,4].

**References:** [1] Neal C.R., Hood L., Huang S. and Nakamura Y., (2006) *NRC White Paper to the Committee on the Scientific Context for the Exploration of the Moon*. [2] Heiken G., Vaniman D.T. and French B.M. (eds.) (1991) **Lunar Sourcebook**, Cambridge University Press, New York, NY, Table 3.2. [3] Lieberman A., Leanna A., McAlonan M. and Heshmatpour B., *Space Technology and Applications International Forum-STAIF 2007*, edited by M.S. El-Genk, 2007 American Institute of Physics 978-0-7354-0386, pages 347-354. [4] Heshmatpour B., Lieberman A., McAlonan M. and Leanna A., *Proceedings of Space Nuclear Conference 2007*, Boston, Massachusetts, June 24-28 2007, Paper 2041, pages 182-191, American Nuclear Society (ANS).