Moon equatorial regions experience wide temperature swings from -180°C to +130°C during the lunar day/night cycle, and the sustained temperature at the shadowed regions of lunar poles can be as low as -230°C. Mars diurnal temperature changes from about -120°C to +20°C. All exploration endeavors, including robotic, habitat, and ISRU systems that are expected to reliably operate on the Moon or Mars surface for years will need electronics that are able to survive and operate in a wide temperature range and thermal-cycling environment. In addition, the electronics must operate reliably after a total ionizing dose (TID) \( \geq 50 \text{ krads (Si)} \) and provide single-event latchup immunity (SEL) \( \geq 100 \text{ MeV cm}^2/\text{mg} \). The lunar and Martian temperatures are well outside the specification range of military and commercial electronics. While many types of devices, especially Si CMOS transistors, can operate down to low temperatures, there are significant circuit design challenges that need to be addressed, especially in the case of mixed-signal and analog circuits.

In addition, thermal cycling present in lunar and especially Mars environments introduces reliability concerns associated with mechanical stress and fatigue of the IC package. For example, compounds optimized for Earth-like packaging of electronic systems have glass transition temperatures that are within the cycling range of these environments, and cycling of electronic systems packaged using these materials will likely result in package failures. Hence, the choice of packaging technology and material combination used is extremely critical for these missions.

Proposals are sought in the following specific areas:

- Wide temperature (-180°C to +130°C) and low-temperature (-230°C), radiation-tolerant and SEL immune, low power, mixed-signal circuits including analog-to-digital converters, digital-to-analog converters, low-noise pre-amplifiers, voltage and current references, multiplexers, power switches, microcontrollers, and integrated command/control/drive electronics for sensors, actuators, and communications transponders.

- High-density packaging able to survive large numbers of thermal cycles (hundreds) and tolerant of the extreme temperatures of the Moon and Mars, including appropriate selection of packaging materials.
combinations (substrates, die-attach, encapsulants, etc.) modular system level electronics packaging, including power, command and control, and processing functions, enabling integration of electronics with sensors and actuators elements.

- Radiation-tolerant, SEL immune, wide temperature (-180°C to +130°C), and ultra-low temperature (-230°C) RF electronics for short range and long-range communication systems.

- Computer Aided Design (CAD) tools for predicting the electrical performance, reliability, and life cycle for low-temperature electronic systems and components.

- Physics-based transistor device models valid at temperature ranging from -230°C to +130°C to enable design, verification and fabrication of custom low power mixed-signal and analog circuits.

- Low-temperature (-230°C) circuit design methodologies facilitating novel layout designs for integrated mixed-signal and analog circuits.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware/software demonstration, and when possible, deliver a demonstration unit for functional and environmental testing at the completion of the Phase 2 contract.