The goals of this topic are to develop advanced space communications and networking technology; high-performance computers and computing architectures for space systems and data analysis; low-power electronics to enable robotic operations in extreme environments; and imaging sensors for machine vision systems and the characterization of planetary resources. Subtopics of this topic area include:

*In-Space Computing and Reconfigurable Electronics*. This subtopic includes architectures and components required for space-based computing and avionics systems. Architecture efforts will emphasize modular, fault-tolerant approaches that leverage commercial standards and COTS devices. Component work will focus on capabilities for enhancing general- and special-purpose processing to meet multiple mission goals. Products of particular interest include reconfigurable electronics, fault-tolerant, reconfigurable processor, micro-controllers and storage devices.

*Extreme Environments/Low Temperature Electronics*. This subtopic includes radiation-tolerant, wide-temperature-range digital, analog, mixed signal, dynamic member and RF electronic components, and integrated modules suitable for operation in the extreme environments of the Moon, Mars and other deep space destinations. Efforts will emphasize supporting electronics for sensors, actuators and communications. The focus of this subtopic is radiation-tolerant, analog, mixed signal, dynamic memory and RF electronic components, and integrated modules suitable for operation in extreme low-temperature space environments.

*Sensing and Imaging*. This subtopic includes orbital remote sensing for topographical and resource mapping and atmospheric profiling and control-loop sensing for robotic functions such as rendezvous and docking, assembly and construction, and precision landing. Products of particular interest include control-loop sensors for position, velocity and force, rapid detection and readout arrays for 2D and 3D imaging at 1.5 µm and multi-wavelength IR and visible laser arrays.

*Surface Networks and Access Links*. This subtopic includes communications technologies to support operational activities in space beyond low Earth orbit and on planetary surfaces in which nodes are simultaneously connected to each other, to Earth, and to the CEV via in-space relay orbiters, and via wired and wireless networks providing the bidirectional voice, video and data needed. The focus of this subtopic is on the modular, reconfigurable RF communications and networking technologies needed to support a human presence on remote lunar and planetary
surfaces with short-range networks and access links to long-haul systems.

Subtopics

X1.01 In-Space Computing and Reconfigurable Electronics

Lead Center: GSFC
Participating Center(s): JSC, MSFC

The goal for this subtopic is the development of advanced space technology to further high-performance computers and computing architectures and reliable electronic systems that can operate effectively for long periods of time in harsh environments. These systems require management of low power and radiation, and must be reliable, robust and reconfigurable.

The objective for this development goal is to elicit novel architectural concepts and component technologies that have realistic potential and achievable applications and are responsive to the priority areas of this subtopic. Technologies will be selected based on the potential that their final end products are sustainable (affordable, reliable/safe and effective), and will advance solutions to the challenges of reusability, modularity and autonomy. Priority areas are:

Data processing

- General purpose processors (piece part, rather than an entire board) possessing fault tolerance at cell and or die levels, floating point and error correction.

- Technologies that reduce the physical size and power requirements of computing systems: making the data system more adaptable, modular, and cost effective.

- New standard models for analysis of interplanetary radiation and radiation belts, and technologies that enable radiation measurements such as total dose and single event effects in computing systems: enhances capability to design radiation tolerant data systems, monitor systems in flight, and predict errors and contingencies.

Reconfigurable Electronics and Implementations

- Reconfigurable designs and architectures that support fault tolerance and are functionally and physically modular.

- Solutions, designed around generic blocks, for recovery from multipoint failures (as opposed to single fault) component failure, where a system can monitor and identify the failing components, and self-repair or bypass small portions of the electronics. These prioritized generic blocks would enable graceful degradation of higher functions while maintaining the system core functionality.

Data System Support Electronics
• Radiation-hard microcontrollers, phase lock loops (PLL), and high-speed oscillators (greater than 150 MHz, equal duty cycle).

• FPGA: Environmentally tested, reliable, tolerant IO, radiation hardened cell structures, Anti-Fuse or reconfigurable.

• Robust and reliable non-volatile storage devices such as EEPROMs and FLASH memory.

Command and Data Transfer

• Inter-system data transfer communications between spacecraft subsystems based on standard interfaces that address high multi-drop throughput (10 to 100 mbps), self diagnosis, inherent redundancy and low power, and support subsystem data transfer to realize higher autonomy.

• Intra-system data transfer communications within the spacecraft subsystems, between cards within a box, to replace the conventional passive backplanes, e.g., switched fabric backplanes with fault detection and serial interfaces.

X1.02 Extreme Environment Electronics/SEE

Lead Center: JPL
Participating Center(s): GSFC, MSFC

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. 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 following specific areas:
• Wide temperature (-180°C to +130°C) and low-temperature (-230°C), radiation-tolerant and SEU immune, low power, mixed-signal circuits including analog-to-digital converters, digital-to-analog converters, low-noise pre-amplifiers, voltage and current references, multiplexors, 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.

• 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.

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 testing at the completion of the Phase 2 contract.

X1.03 Sensing and Imaging

Lead Center: JPL
Participating Center(s): GSFC, LaRC

Sensing and imaging systems can provide a number of capabilities required for anticipated NASA missions including exploration of Mars and the Moon. Capabilities of interest include the following:

• Orbiting sensors to map:
  - Extent and concentration of useful, surface, or subsurface resources to identify promising outpost or science sites and traversable terrains;
  - Surface topography and roughness to identify promising safe landing sites for human, robotic science, and pre-provisioning missions, and to guide pinpoint landing algorithms.

• Robot-mounted sensors for: estimating robot pose and motion; recovering 3D scene structure; identifying hazards or objects of interest; identifying articulation of observed objects, and performing visual serving. Flight ready (radiation and temperature hardened), high cycle rate, and low power systems are generally preferred. Applications include:
- Autonomous rendezvous and docking;
- Pinpoint landing;
- Surface navigation;
- Surface and on-orbit assembly/construction;
- Resource mining/processing;
- Multi-vehicle cooperation.

Specific technologies of interest in addressing these challenges include:

- Rapid frame rate arrays for 1, 1.5 and 2 µm vision (2D and 3D);
- Multi-wavelength laser arrays;
- Flight-ready, high-speed, medium-resolution (640x480) stereo-vision sensors;
- Flight-ready, low-power lighting systems (headlights) to allow imaging during nighttime robotic operations;
- Tightly coupled inertial and vision sensors for pose estimation;
- Ground truthing systems for evaluating performance of ranging systems.

A number of related technologies are of interest but are covered under other subtopics, including:

- High power or high rep-rate lasers (S6.02, S1.04);
- Ultra-high sensitivity detectors and arrays (S4.01);
- Active and passive microwave sensors (S6.04, S6.05).

---

**X1.04 Surface Networks & Access Links**

Lead Center: GRC

Participating Center(s): GSFC, JPL, JSC

To develop safe and sustainable exploration capabilities at minimum cost, while maximizing return, an incremental spiral development process will guide a build out of an integrated communication, navigation, networking, computing, informatics, and power architecture that supports all surface and proximity nodes, including humans in spacesuits, robots, rovers, human habitats, satellite relays, and pressurized vehicles.
The architecture will enable operational activities in which both fixed and mobile nodes with vastly differing communications requirements are seamlessly interoperable. Nodes are simultaneously connected to each other, to Earth, and to the CEV via in-space relay orbiters, and via wired and wireless networks that provide the bidirectional voice, video, and data needed. The need to be self-sufficient during exploration requires local control and an unprecedented level of autonomous operation to seamlessly connect the nodes and reduce operations cost. The Moon and Mars environments require SEU and extreme temperature-tolerant equipment tightly constrained by power, mass, and volume. Human presence requires at least one usable bidirectional link to the communications network at all times and high definition video to engage the public interest.

This subtopic focuses on the modular, reconfigurable RF communications and networking technologies needed to support a human presence on remote lunar and planetary surfaces with surface-to-surface and surface-to-orbit (access) communications.

**Surface Networks**

The complexity of astronaut excursions, habitats, surface manned and unmanned rovers, and landers make surface operations and man-occupation complex and daunting tasks. Exploration of planetary surfaces will require short-range, bidirectional, multi-point links to provide on-demand, autonomous interconnection among surface-based assets. Some of the nodes will be fixed (base stations) and some will be moving (rovers and humans). This will encompass a number of communications and networking technologies for communications in the 2.4 Ghz range, including: integrated low mass, low power (100's of milliwatts) transceivers for very short-range interfaces with sensors and other small devices; power-efficient, miniature, modular transceivers for short-range communications among large (e.g., lander) and medium-sized (e.g., rover) surface assets; reconfigurable directionally selectable, multi-frequency arrays for wide coverage, high-gain links among surface assets; miniaturized modular antenna technology for surface-to-surface communications among mobile and fixed nodes; wireless products integrated with low-power space-rated ASICs and FPGAs; short (~1km) range access point base stations, or wireless router bridges for extending surface network coverage; fixed, long (~50km) range, wireless network terminals for extending high data rate communications over large distances; self-healing ad-hoc network MAC and protocols for intelligent, autonomous link management; and networking technologies to enable autonomous, seamless interconnectivity among all nodes.

**Access Links**

To interface with orbiting relays, terminals capable of providing seamless connectivity between surface networks and orbiting relays will be positioned on lunar and planetary surfaces and in orbit. Such an access link communications system will include: high rate, efficient, solid state amplifiers capable of very high data rates over 1,000-10,000 km distances with ranging signals embedded; very low-power data rates, and cost inter-spacecraft S-band transceivers/transponders for inexpensive spacecraft; optical transceivers capable of very high data rates over 1,000-10,000 km distances; SEU and solar flare tolerant transponders capable of: programmable wide-carrier frequency ranges from S-band to Ka-band, taking GPS measurements, and handling IP at the digital level; micro software radio technology for autonomous and intelligent space applications; low mass, volume, power, and cost-stable oscillators to provide accurate time and frequencies for autonomous operations; autonomously reconfigurable receivers capable of automatic link configuration and management; microwave ranging hardware built into communication systems for rendezvous and collision avoidance; and ad hoc long range spacecraft-to-spacecraft network protocols to setup links on demand, such that each node can route data through to another node.