NASA SBIR 2006 Phase I Solicitation

Space Operations

Space Communications Topic O1
NASA's communications capability is based on the premise that communications shall enable and not constrain missions. Communications must be robust to support the numerous missions for space science, Earth science and exploration of the universe. Technologies such as optical communications, RF including antennas and ground based Earth stations, surface networks, access links, navigation and timing, reprogrammable communications systems, communications systems for EVAs, advanced antenna technology and transmit array concepts, communications in support of launch services including space based assets are very important to the future of the exploration and science activities of agency. Also operational issues associated with the communications capability are needed. Communications that enable the range safety data from sensitive instruments is imperative. These technologies are to be aligned with the Space Communications and Navigation Architecture as being developed by the agency.

Sub Topics:

O1.01 Coding, Modulation, and Compression

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

Power and spectrum efficient solutions are needed for both near-Earth and deep-space science and exploration applications. Channel coding efficiency from 50% to 87%, combined with good bit-error/burst-error correction property will provide solutions to multiple missions. A high-speed, digital receiver capable of demodulating coded modulations in addition to un-coded modulations is needed for future missions. In compression, implementation of a high-speed decoder for decoding a standard embedded bit-stream offering tunable lossy compression to lossless compression is desired. Proposals are sought in the following specific areas:

Compression

High-speed decoder capable of decoding coded bit stream conforming to CCSDS 122.0-B-1 Image Data Compression standard (www.ccsds.org [1]) is solicited. The decoder has to provide over 640 Mbits/sec decoding for up to 16-bit image data coded in an embedded bit stream. The decoder shall not consume more than 5 watts of power at the specified speed. The implementation technology shall point to potential space-use feasibility.

Coding

Special emphasis is placed on a channel coding design suitable for near-Earth missions, operating at least at over 80% coding rate with an error floor lower than Bit-Error-Rate (BER) of $10^{-10}$, and at least 8-bit burst-error correction property, with encoder/decoder complexity consistent with implementations at data rates close to 1 Gbps and power consumption smaller than a few watts. The new design when compared with current CCSDS Reed-Solomon (255,223) coder at BER of $10^{-5}$ shall have over 2dB Eb/No gain. The preferred code block frame length is from 4K to 16K bits. Proposed implementation technology shall point to potential space-use feasibility.
High-Rate Receiver

High-rate receiver capable of decoding coded and un-coded modulation suite (8-PSK, GMSK, filtered OQPSK) specified by CCSDS 413.0-G-1 April 2003 (www.ccsds.org [1]) and 16-PSK, 16-QAM, 16-APSK with processing throughput greater than 300 Mbits/sec is desired. A desirable feature for the receiver output is 7 bits/sample that can be used as input to channel decoding algorithms based on soft-decision decoding.

O1.02 Precision Spacecraft Navigation and Tracking

Lead Center: GSFC

This call for proposals is meant to serve NASA's ever-evolving set of missions, which require precise tracking of spacecraft position and velocity in order to achieve mission success. The call seeks evolutionary improvements in modularity, sustainability, cost, and performance for current space navigation concepts that support the Vision for Space Exploration. This includes Projects Constellation, Prometheus, robotic servicing, and robotic Earth and space science missions. NASA also seeks disruptive navigation concepts that might not match the modularity, sustainability, cost, and/or performance of current technologies and their near-term evolution, but have convincingly demonstrable potential to overtake the evolution of current technologies within the future development of Projects Constellation and Prometheus, and Earth and space science missions, in the 2015 - 2020 timeframes.

While the definition of "precise" depends upon the mission context, typical interplanetary scenarios have required Earth-based radiometric ranging accuracies of order 1-2m at 1 AU, Doppler to 0.03 mm/sec, and plane-of-sky angles to 2.5 nano-radians. While some legacy applications remain at 2.3 GHz, most current tracking is being done at 8.4 GHz. Forward looking demonstrations are being planned at 32 GHz. These radiometric techniques have been complimented by optical techniques which achieve ~1.5 micro-radian angular accuracy upon target approach. The accuracy of radio-based techniques is typically limited by one's ability to calibrate the path delay through intervening media (troposphere, ionosphere) and by the phase stability of electronics in both the spacecraft and ground systems. For both media and electronics, the stability goal is to achieve Allan standard deviations of 4e^{-15} at 100 seconds and 1.5 e^{-15} at 1e^{3} to 1e^{4} seconds while maintaining, or improving upon, current levels of reliability.

Space navigation technology concepts should support launch and return to Earth, including range safety, early orbit operations, in-space assembly, cis-lunar and interplanetary transit, lunar and planetary approach and orbit, ascent and descent from lunar and planetary surfaces, including precision landing, lunar and planetary surface operations, automated rendezvous and docking, and formation flying spacecraft forming synthetic apertures for science imaging and interferometry. NASA considers applicability to multiple operational regimes through modularity and/or missionization of common components a key element in its exploration strategy. Space navigation systems must produce accurate long-term trajectory predictions as well as definitive epoch solutions. Where applicable, proposed concepts should be interoperable with and/or leverage the resources of NASA's space communications architecture. All navigation systems should be compatible, where applicable, to continuous or near-continuous trajectory perturbations generated by onboard spacecraft systems. All concepts must show some significant advantages over current techniques in at least one of the following areas: accuracy, cost, reliability, modularity, sustainability, or for onboard systems, mass, power, and volume.

Innovative technologies are sought in the following areas:
Highly phase-stable RF ground systems are critical to high accuracy radiometric tracking. Present systems rely upon analog transmission over 0.5 to 10 km distances of a broadband (100 - 600 MHz) spectrum. Transmission induced phase errors could be greatly reduced by developing highly phase stable digital sampling and time tagging systems that can be placed near (~10m) to the RF feedhorn without measurably degrading the RF signal capture with spurious tones and noise. Phase stability goals are given above. The sampler should Nyquist sample the 100 - 600 MHz band with at least 8-bit resolution and be capable of digitally transmitting the resulting samples over fiber optic lines;

The VLBI parameter estimation software used to build the radiometric reference frames used for precise tracking relies on a Square Root Information Filter that makes use of Householder transformation techniques. These solutions often take several days of CPU on a modern workstation. Block matrix techniques have the potential to optimize the interaction of the CPU and cache memory thereby greatly reducing the CPU time needed for solutions. The goal is a factor of three improvement in total solution time for problems with 7 million data points and 500,000 parameters, which include at least 5000 parameters that are active over the entire data set;

Microwave radiometry of atmospheric emission lines (22 GHz H_2O, 60 GHz O_2) has been successful in demonstrating 1 mm level calibration of tropospheric path delay. However, the usefulness of this technique has been limited by the large mass and size of the instrument packages. Identifying/developing low mass, low cost implementations of this technique without significantly sacrificing accuracy would greatly enhance precise tracking;

Develop low mass, (Less than 1 kg) low cost onboard radio frequency standards for generating highly phase-stable onboard radio signals which achieve Allan standard deviations of $1 \times 10^{-15}$ at 1000 seconds and drift of less than $10^{-15}$/day;

Develop innovative tracking technologies using new wavelengths (X-ray, Infra-red, etc.), such as systems using celestial and planetary emissions and reflections (not limited to the visible spectrum) that can produce three-dimensional absolute and relative position and velocity in regions where Earth-based GPS measurements are not available. The technologies can exploit either ground based or on-board techniques;

Develop innovative technologies for improving the state of the art in terms of cost and performance in making spacecraft-to-spacecraft measurements, such as omni-directional range and bearing sensors and robotic-vision-based systems; and

Develop innovative navigation algorithms and software supporting analysis, design, and mission operations that will reduce operations costs and support multiple systems in simultaneous, tightly-coupled, non-quiescent operations, such as robotic servicing and formation flying.

O1.03 Communication for Space-Based Range

Lead Center: GSFC
Participating Center(s): AFRC, KSC

Metric tracking of launch vehicles for range safety purposes is currently based on redundant radars, telemetry receivers, and uplink command transmitters at the launch site with additional assets deployed downrange in order to maintain line-of-sight communications with the vehicle as it passes over the horizon to orbital insertion.
The vision of space-based range architecture is to assure public safety, cut the costs of launch operations, decrease response time, and improve geographic and temporal flexibility by reducing, or eliminating, these assets. In order to achieve this, a number of advancements in tracking and telemetry are required. Some of NASA's needs are:

**GPS/IMU Metric Tracking and Autonomous Systems**

Realization of a space-based range requires development of GPS receivers that incorporate:

- Low power consumption;
- Low mass/volume;
- Compliance with range safety standards;
- Flexible tracking loop programmability;
- Programmable output formats; and
- Operability in high G environments.

Other highly desirable GPS specific characteristics include open architecture supported by development software and the capability of being incorporated onto circuit boards designed for multiple functions.

Tactical grade IMUs are needed which can function on spin-stabilized rockets (up to 7 rps) and reliably function during sudden jerk and acceleration associated with launch and engine firings and can be coupled with GPS receivers.

Also needed are approaches to processing the outputs of navigation sensors and combining them with rule-based systems for autonomous navigation and termination decision making.

**Space-Based Telemetry**

Small, lightweight, low cost transceivers capable of establishing satellite communications links for telemetry and control during the launch and assent stages of flight are required to provide unbroken communications throughout the launch phase. These may enable use of the NASA TDRSS, or commercial communications satellites.

Techniques for multiplexing narrow bandwidth channels to permit increased bit rates and improved algorithms for ensuring smooth transition of support between communications satellites are also needed.

**GPS Attitude Determination for Launch Vehicles**
Investigate using inexpensive arrays of GPS antennas and receivers on small, expendable launch vehicles to determine the attitude angles and their rates of change as an alternative to traditional inertial measurement units.

The system should be contained entirely on the vehicle and not rely on ground-based processing. The attitude accuracy should be comparable to gyroscope-based systems and should be free of drift and gimble lock. The system must be able to maintain attitude output during periods of high dynamics and erratic flight. The attitude must be determined at a rate of least 10 Hz with minimal processing delay and must be output in a format compatible with vehicle telemetry systems.

**O1.04 Antenna Technology for Spacecraft and Planetary Surface Vehicles**

**Lead Center:** GRC

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

NASA seeks advanced antenna systems for use in spacecraft and planetary surface vehicles used in science, exploration systems, and space operations missions. Future manned missions to the Moon and Mars will have stringent communication requirements. Highly robust communication networks will be established in the vicinity of the planet to support long-term human interplanetary mission. Such networks will consist of a large number of communication links that connect the various network nodes. Some of these nodes must also maintain continuous high data rate communication links between the moon and the Earth. Great demands will be placed on these communication systems to assure crew safety, robustness in harsh environments, and high reliability for long duration manned missions.

Areas of interest include lightweight deployable antenna systems, high-gain antenna architectures, multi-frequency and dual polarized antennas, self-orienting systems, reconfigurable antennas, novel concepts, antennas that can adapt to failed components without compromising performance and operability (e.g., smart antennas that include structural health monitoring and active control). NASA seeks to develop a lightweight scanning phased array antenna system that enables assured communication links for human interplanetary exploration.

NASA is also interested in technologies enabling direct conversion of RF signals to digital and advanced concepts wherein such systems are integrated with novel smart antenna concepts to allow true interoperability and reconfigurability in the sense of software radios.

Antenna systems for novel navigation concepts (e.g. pulsar beacons) as well as integrated communications and navigation architectures are desirable.

Large inflatable membrane antennas to significantly reduce stowage volume, provide high deployment reliability, and significantly reduced mass (i.e.

High efficient, miniature antennas with smaller than lambda square aperture size, to provide astronauts and
robotics communications for surface to surface and surface to orbit for lunar, Mars, and planetary exploration missions. Recent new antenna research and development has shown that it is possible to design and build aperture antennas with smaller than the minimum effective apertures size of dipoles. This new class of antennas can provide higher antenna gains (> 2.5 dBi) than the dipole antenna in much smaller aperture size (The architecture for lunar exploration as defined by the Space Communication Architecture Working Group (SCAWG) is expected to involve a layered communications and navigation network. This network may include lunar vicinity relay satellites at L1 and L2 Lagrange points as well as lunar polar orbiting satellites. The lunar proximity network must be able to access dedicated assets such as Malapert Station and eventually include human assets, such as crewed rovers, as relay nodes. Consequently there is an interest in antenna technologies that enable low cost but reliable reconfigurable and agile antennas at frequencies up to 38 GHz. Another component technology that shows high interest in the area of Earth and planet science is thin-membrane mountable T/R modules, phase shifters, beam former, control circuitry, etc. for future deployable/inflatable large-aperture phased array application. This topic seeks novel smart antenna concepts to address the aforementioned requirements. There is also interest in space-to-surface links at 25.5 GHz and 37 GHz. The size of reflector antennas is limited by the accuracy of the reflector surface that can be achieved and maintained on-orbit. Development of special materials and structural techniques to control their environment, etc., reduces environmentally induced surface errors and increases the maximum useable reflector size. Distortions caused by thermal gradients are inherently a large scale phenomenon. The reflector surface is usually sufficiently accurate over substantially large local areas but these areas are not on the same desired parabolic surface. An array of feed elements can be designed to illuminate the reflector with a distorted spherical wave. This distortion can be used to compensate for large scale surface error introduced by thermal gradients, gravitational and other forces, and manufacturing. Topics of interest include but are not limited to: Compensating Feed System for an Antenna Reflector Surface With Large Scale Distortions; Techniques for the remote Measurement of Satellite Antenna Profile Errors; Determination of Orbits S/C Antenna Distortion by Ground-Based Measurements; Measuring and Compensating Antenna Thermal Distortions; Reflector Measurements and Corrections using arrays; Reflector Distortion Measurement and Compensation Using Array Feeds.

NASA is interested in low cost phased array antennas for suborbital vehicles such as sounding rockets, balloons, UAV's, and expendable vehicles. The frequencies of interest are S-band, Ku-band, and Ka-band. The arrays are required to be aerodynamic in shape for the sounding rockets, UAV's, and expendable platforms. The balloon vehicles primarily communicate with TDRS and can tolerate a wide range of mechanical dimensions.

Antenna pointing techniques and technologies for Ka-band spacecraft antennas that can provide spacecraft knowledge with sub-milliradian precision (e.g., NASA is designing arrays of ground-based antennas to serve the telecommunications needs of future space exploration. Medium-size (12m class) antennas have been selected for receiving, and arrays of hundreds of them are expected to be required. Applications include communication with distant spacecraft; radar studies of solar system objects; radio astronomy; and perhaps other scientific uses. A significant challenge is the implementation of an array for transmitting (uplinking), which may or may not use the same antennas that are used for receiving. The uplink frequency will be in the 7.1 - 8.6 GHz band (X-band) in the near term and may be in the 31.5 - 33.0 GHz band (Ka-Band) in the future; it will likely carry digital modulation at rates from 10 kbps to 30 Mbps. An EIRP of at least 500 GW is required, and some applications contemplate an EIRP as high as 10 TW. It is also desirable to support as many as ten simultaneously-operating deep-space missions from one complex on Earth, and to have at least three geographically separated complexes so communication is possible with a given spacecraft at any time of the day. The major open questions in the uplink array design are:
Minimizing the life-cycle cost of an array that produces a given EIRP by selecting the optimum combination of antenna size, transmitter power, and number of antennas. This becomes much more difficult if the option of using the same antenna for both uplink and downlink is considered;

Identifying/developing low-cost, highly reliable, easily serviceable components for key systems. This could include highly integrated RF and digital signal processing electronics, including mixed-signal ASICs. It could also include low-cost, high-volume antenna manufacturing techniques. (For the receiving array, another key component is a cryogenic refrigerator for the 15 - 25K range.) Also, low-cost transmitters (including medium-power of the order of 100s of Watts) amplifiers are key;

Phase calibration techniques are required to ensure coherent addition of the signals from individual antennas at the spacecraft. It is important to understand whether space-based techniques are required or ground-based techniques are adequate. In general, a target spacecraft in deep space cannot be used for calibration because of the long round-trip communication delay;

Design of ultra phase-stable electronics to maintain the relative phase among antennas. These will minimize the need for continuous, extensive and/or disruptive calibrations;

Understanding the effect of the medium (primarily the Earth’s troposphere) on the coherence of the signals at the target spacecraft. Generally, turbulence in the medium tends to disrupt the coherence in a way that is time-dependent and site-dependent. A quantitative understanding of this is needed; and

Techniques for integrating a very low-noise, cryogenically-cooled receiver with medium power (1W to 200W) transmitter. If transmitting and receiving are combined on the same antenna, the performance of each should be compromised as little as possible while maintaining low cost and high reliability.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration that will, when appropriate, deliver a demonstration unit for testing at the completion of the Phase 2 contract.

O1.05 Reconfigurable/Reprogrammable Communication Systems

Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC

NASA seeks novel approaches in reconfigurable, reprogrammable communication systems to enable the Vision for Space Exploration, Science, and Space Operations. Exploration of the Moon and Mars will require advancements in communication systems to manage the demands of the harsh space environment on space electronics, maintain flexibility and adaptability to changing needs and requirements, and provide flexibility and survivability due to increased mission durations. NASA missions can have vastly different transceiver requirements and available resources depending on the science objective, operating environment, and spacecraft resources. For example, deep space missions are often power constrained; operating over large distances, and subsequently have lower data transmission rates when compared to near-Earth or near planetary satellites. These requirements and resource limitations are known prior to launch; therefore, the scalability feature can be used to maximize transceiver efficiency while minimizing resources consumed. Larger platforms such as vehicles or relay spacecraft may provide more resources but may also be expected to perform more complex functions or support multiple and simultaneous communication links to a diverse set of assets.
This subtopic seeks advancements in reconfigurable transceiver and component technology, providing flexible, reconfigurable capability while minimizing on-board resources and cost. The use of open standards within the software radio development is desirable while minimizing potential increased resources and inefficiencies. Topics of interest include the development of software defined radios or radio subsystems which demonstrate reconfigurability, flexibility, reduced power consumption of digital signal processing systems, increased performance and bandwidth, reduced software qualification cost, and error detection and mitigation techniques. Complex reconfigurable systems will provide multiple channel and simultaneous waveforms. Areas of interest can be divided as follows:

**Signal Waveforms and On-Orbit Reconfiguration**

- Multiple waveforms and multiple channel support strive to reduce radio count to reduce power consumption of the overall communication system. Tradeoffs in radio count and radio complexity are considered in the analysis. Reconfiguration for software and firmware upgrades shall provide access control, authentication, and data integrity checks for the reconfiguration process. Partial reconfigurable logic allows simultaneous operation and upload of new waveforms or functions. Upon operator or automated load detection failure, capability to provide access back to a known, reliable operational state is needed. An automated restore capability ensures the system can revert to a baseline configuration, thereby avoiding permanent communications loss due to an errant reconfiguration process. Approaches should minimize size and power consumption for deep space transceivers incorporating fault tolerant, reprogrammable digital signal processing devices.

- Implementations demonstrating the concept function, and benefits of dynamic or distributed on-board processing architectures to provide maximum reconfigurability and processing capacity are sought. A common processing system capacity for communications, science, and health monitoring is envisioned.

- Demonstration of adaptive modulation and waveform recognition techniques are desired to provide capability to reconfigure to the waveform identified based on an on-board library or enable new waveform upload to the on-board library from the ground.

**Software Architecture, Implementation, Modeling and Verification**

- Development and demonstration of low overhead, low complexity hardware and software architectures to enable software component or design reuse, or common testing standards that demonstrates cost or time savings. Emphasis on the application of open standards architecture to facilitate interoperability among different vendors to minimize the operational impact of upgrading hardware and software components.

- Methods that enable portability among reconfigurable logic hardware devices among different vendors, different device families and types of digital processing technologies.

- As the use of software and firmware increases with more flexible and portable software defined radio technologies, methods are sought to reduce the complexity and cost to space qualify and verify software operation for use in space yet maintain or increase on-orbit reliability.

- Techniques to ensure reliable software execution and failure detection and self-correction.

- One promise of a software defined radios is software and design reuse maintained in a common repository. The cost or ability to reuse software depends on implementation, development practices, code complexity and other circumstances. This subtopic seeks the development and demonstration of software tools or tool chain methodologies to enable both design and software code reuse.
Fault Tolerance

- The use of reconfigurable logic devices in software defined radios is expected to increase in the future to provide reconfigurability and on-orbit flexibility for waveforms and applications. As the densities of these devices continue to increase and feature size decreases, the susceptibility of the electronics to single event effects also increases. Novel approaches to mitigate single event effects caused by charged particles are sought that reduces power consumption and complexity compared to traditional approaches (i.e., voting schemes and constant updates (scrubbing)).

- Techniques and implementations to provide a core waveform capability within the software defined radio in the event of failure or disruption of the primary waveform and/or system hardware. Communication loss should be detected and core or "gold" waveform automatically executed to provide control access to diagnosis system and over-the-air reload operational waveform and control software.

Radio Architectures

- Innovative solutions to provide software defined radio implementations to reduce power consumption and mass. Solutions should promote modularity and common, open interfaces.

- Software defined radio implementations that enable future hardware scalability among different mission classes (e.g., low rate deep space to moderate or high rate near planetary, or relay spacecraft). Operational characteristics range from 1’s to 10’s Mbps at UHF and S-band frequency bands up to 10’s to 100’s Mbps at X, and Ka-band frequency bands.

Component Technology

- Advancements in analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities while reducing power consumption.

- Novel techniques to advance memory densities, reduce power consumption, and improve performance in harsh environments.

- Advancements in reconfigurable logic technology including processing advancements, radiation hardened commercial technology and advancements in advanced computing such as polymorphous computing.

O1.06 Extravehicular (EVA) Radios

Lead Center: JSC

Participating Center(s): GRC

This subtopic focuses on dramatically shrinking the size of the EVA radio by selecting and using micro-machined RF components in the development of a Phase 1 circuit design which demonstrates compact high Q selective...
devices to propose for Phase 2 to fully fabricate and demonstrate a prototype radio incorporating the compact high Q filter technology developed and demonstrated during Phase 1. This subtopic seeks proposals to close a critical technology gap in the ability to reduce the form factor and power requirements of the EVA Radio while increasing its selectivity and performance, enabling long duration human exploration while simultaneously increasing communications reliability and crew safety.

Miniature EVA Radio

Human exploration demands versatile, lightweight, and miniaturized EVA Radios to enable surface operations and increase astronaut mobility. The size, weight, and power consumption of EVA Radios must dramatically decrease to reduce overall mission costs. These EVA Radios cannot sacrifice performance for weight, power, and form factor requirements - in fact, quite the opposite. While the form factor shrinks, the performance must increase to handle the combination of voice, data, and video needed to support the complex tasks in the next generation of manned mission scenarios.

EVA Radios based on micromachined RF components eliminate the most bulky pieces - the RF components in the diplexers, pre-selectors, and bandpass filters. For example, most high rejection diplexers for space-based radios are almost as enormous as the modern radio package itself. Micro-machined RF elements can complement space radio technology by coupling high-performance and increased reliability with reduction in size.

Besides low spatial volume, a significant mass reduction, and low-power consumption, micro-machined RF devices are also attractive to operate as high Q components to perform frequency selectivity without mass penalties. To build and design high performance, tightly coupled, low volume space radios, compact selectivity-determining devices are a critical enabler. Most high Q filters above 400MHz, such as inter-digital filters and others involving resonant cavities, tend to be wholly mechanical assemblies whose size is generally governed by their frequency and some derivative of their resonate wavelength. By applying micro-machining techniques, the same filter assemblies employing advanced 3D packaging techniques can be "folded" in the design, which is conducive to an order of magnitude improvement in utilization of EVA radio volumetric space.

New EVA Radio Capability

The intent of this subtopic is to develop, apply and demonstrate advantages of micro-machined RF component-based circuitry that proliferate the implementation of next-generation lightweight EVA radios. Areas of investigation may include electromechanically tuned filters, 3D packaged, micro-machined RF resonators, filter configurations consisting of cantilevered structures, as well as carbon nanotube waveguide assemblies. Through application of these fabrication and packaging techniques great strides will be realized in improving functionality, enhancing performance and achieving high reliability for long duration manned space missions. Miniature EVA Radio features include:

- Dramatic reduction of mass;
- Dramatic reduction in power requirements;
- High selectivity components, reducing interference and overlap;
- High reliability through Fault Tolerant design;
- Frequency agility;
- Software defined waveforms and modulation/demodulation.

**Technical Approach**

The design and use of circuitry using micro-machined RF components to dramatically shrink EVA Radio form factor while increasing operational performance will be supported by investigations and trade studies selecting current and near-term micro-machined RF components, culminating in a circuit design demonstrating their use to make a high Q element. Phase 2 will harness the high Q element as a model; then design an overall EVA Radio architecture compliant with Space Transportation Radio System (STRS) embracing a fault tolerant hardware design. The tradeoffs in sensitivity, selectivity, and packaging will be investigated in the Phase 2 effort.

**Commercialization Plan**

By providing users with a small size, low power, high performance SDR-based radio platform, the miniature EVA radio has derivative uses far beyond the scope of space exploration. The combination of micro-machined RF assemblies and 3D packaging in the miniature EVA radio has vast implications for both future space exploration and commercial wireless and mobile radio communications:

First Responders: Interoperability among Police, Fire, HazMat, Homeland Security, and Medical personnel

Military: Soldier-centric secure communications, mode switchable on-the-fly

Commercial: Cell phones, pagers, Wi-Fi/Bluetooth/UWB radio integration

**O1.07 Transformational Communications Technology**

**Lead Center:** GRC

**Participating Center(s):** JSC

NASA seeks revolutionary, highly innovative, "transformational" communications technologies that have the potential to enable order of magnitude performance improvements for exploration systems, science, and space operations mission applications. Research focuses on (but not limited to) the following areas:

- Innovative methods of using X-ray or radio pulsar signals for precise navigation or positioning of spacecraft. Small, low mass, reliable detectors, improvements in position accuracy, digital signal processing advances for time of arrival, drift estimation, and position estimation.

- Development of nano-scale communication devices and systems (e.g., FET arrays, nano-antennas, nano-transceivers, etc.) for nano-spacecraft applications.
Quantum entanglement or innovative breakthroughs in quantum information physics to specifically address curious effects and critical unknowns relevant to revolutionary improvements in communicating data, information or knowledge between independent entities across space-time. Methods or techniques that demonstrate extremely novel means of effectively packaging, storing, encrypting, and/or transferring information or knowledge.

Breakthrough power-efficiency in communications brought about through the use of natural phenomenon, e.g., soliton pulse/wave/energy propagation.

Innovative uses of radiofrequency spectrum, planetary atmospheres, or planetary electromagnetic properties for the breakthrough communication of data, information or knowledge directly between independent entities.

RF Micro Electro-Mechanical Systems (MEMS) devices. Besides low spatial volume, lightweight, and low-power consumption, these devices are also attractive to operate as high Q components and perform frequency selectivity - namely, agile pre-selectors, multi-couplers, and diplexers. Selectivity, or Q, for band pass filters currently comes at an unacceptably high penalty in size and mass. For example, most high rejection diplexers for space-based radios are almost as enormous as the modern radio package itself. To build and design high performance, tightly coupled, low volume space radios, compact selectivity-determining devices are a critical enabler. Most high Q filters above 400MHz, such as inter-digital filters and others involving resonant cavities, are wholly mechanical assemblies which can be “folded” in their design and lend themselves to micro machining techniques.

Other rich areas of investigation may lie within the area between MEMS and Micro-Machined devices, including electromechanically tuned filters, 3D micro machined RF resonators, filter configurations consisting of cantilevered structures, as well as carbon nano-tube waveguides. Develop, apply and demonstrate advantages of RF MEMS circuitry that proliferate the implementation of next-generation lightweight communications systems (e.g. extravehicular activity (EVA) radios).

O1.08 Long Range Optical Telecommunications
Lead Center: JPL
Participating Center(s): GRC, GSFC
This subtopic seeks innovative technologies for long-range optical telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- Space-qualifiable, efficient (greater than 25% wall plug), lightweight, variable repetition-rate (1 - 60 MHz), tunable (± 0.1 nm) pulsed 1064 nm transmitter sources (diode-pumped fiber amplifier or bulk crystal laser/amplifier) with greater than 1 kW of peak power per pulse (over the entire pulse-repetition rate), and greater than 10 W of average power, and narrow (5%);
- Space-qualifiable, high-peak power (> 1.2 W), average-power (> 300 mW), operating wavelength less than 1000 nm single-mode-fiber pigtailed laser diode transmitters (includes necessary modulator; internal or external driver) with narrow spectral width (25%);
- Space-qualifiable, photon counting 1064 nm and/or 1550 nm detectors a temperature of 220 K or greater, with the gain greater than 3000, detection efficiency greater than 50%, dark rate 2 active area, > 0.2 mm in active area diameter, bandwidth greater than 500 MHz, saturation levels > 50 Mcounts/s and non-gated
(continuous operation), and lifetime > 3 years at 100 Mega photons /sec continuous photon flux;

- Lightweight, compact, high precision (less than 0.1 micro-radian), high bandwidth (0-2 kHz), inertial reference sensors (angle sensors, gyros) for use onboard spacecraft;

- Novel schemes for stray-light control and sunlight mitigation, especially for large (> 5 m) ground-based optical telescopes that must operate when pointed to within a few (about 3) degrees of the Sun;

- Lightweight, high precision (one micro-radian accuracy) star-trackers for spaceflight application that can be integrated with an optical communications terminal;

- Novel techniques and technologies that will enable very low cost, large aperture (> 5 m equivalent aperture diameter) telescopes for ground or space-borne use;

- High power ground-based, relatively low-cost diode-pumped laser technology capable of reaching 100 kW average power levels in a TEM$_{00}$ mode, for uplink to spacecraft;

- Artificial laser guide-star and beam compensation techniques capable of removing all significant atmospheric turbulence distortions (tilt and higher-order components) on an uplink laser beam;

- Novel techniques to reduce the development cost and risk of future space-borne optical communications transceivers (e.g., automatic focusing or alignment techniques); and

- Systems and technologies relating to sub-microradian pointing, acquisition, and spacecraft vibration.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration that will, when appropriate, deliver a demonstration unit for testing at the completion of the Phase 2 contract.

O1.09 Long Range Space RF Telecommunications

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

This subtopic seeks innovative technologies for long-range RF telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- Ultra-small, low-cost, low-power, modular deep-space transceivers, transponders, and components, incorporating MMICs and Bi-CMOS circuits;

- MMIC modulators with drivers to provide large linear phase modulation (above 2.5 rad), high-data rate (10 - 200 Mbps), BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (32 GHz and 38 GHz);

- High-efficiency (> 70 %) Solid-State Power Amplifiers (SSPAs), of both medium output power (10 - 50 W) and high-output power (150 W - 1 KW), using power combining techniques and/or wide-bandgap semiconductor devices at X-band (8.4 GHz) and Ka-band (32 GHz and 38 GHz);
• Traveling Wave Tube Amplifiers (TWTAs), SSPAs, modulators, and MMICs for 26 GHz Ka-band (lunar communication);

• TWTAs operating at millimeter wave frequencies and at data rates of 10 Gbps or higher;

• Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends (MEMS-based RF switches and photonic control devices needed for use in reconfigurable antennas, phase shifters, amplifiers, oscillators, and in-flight reconfigurable filters. Frequencies of interest include S-, X-, Ka-, and V-band (60 GHz). Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.

O1.10 Surface Networks and Orbit Access Links

Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC

NASA is planning a series of short and long duration human and robotic missions to explore the Moon and later Mars. The lunar and Mars surface and access network architectures will enable operational activities in which nodes are simultaneously connected to each other, to Earth, and to the Crew Exploration Vehicle (CEV) via in-space relay orbiters, and wired and wireless networks that provide the bidirectional voice, video, and data services. This subtopic is divided into the surface networks and access link domains (surface to orbiting assets).

Surface Networks

Exploration of lunar and planetary surfaces will require short-range, bidirectional, and robust multi-point links to provide on-demand, disruption tolerant, and autonomous interconnection among surface-based assets. Some of the nodes will be fixed (base stations and relays to orbital assets) and some will be moving (rovers and humans). The ability to meet the demanding environments presented by lunar and planetary surfaces will encompass the development and integration of a number of communications and networking technologies and protocols, including:

• Low mass/power (100's of milliwatts) transceivers for very short range interfaces with sensors and other small devices to enable communications among humans, robots, and access network terminals;

• Reconfigurable, directionally selectable, steerable, multi-frequency switched patch or multiple-in multiple-out antenna arrays for human helmets, robots, and fixed structures (e.g. habitats);

• Miniaturized planar, omni-directional, dual-polarized, self-orienting, and sector antennas for surface-to-surface communications among mobile and fixed nodes;

• Low power space rated ASICs and FPGAs for wireless network products; short (Fixed, long (up to 50km) range, wireless network terminals for extending high data rate communications over large distances;

• Integrated, autonomous tracking and navigation architectures and technologies;

• Self-healing, ad-hoc, disruption tolerant network protocols for intelligent, autonomous link management and
Access Links

Lunar and planetary surface networks will need to seamlessly interface with communications access terminals and orbiting relays that can provide autonomous and disruption tolerant connectivity to Earth based assets. The access link communications system will encompass the development and integration of a number of communications and networking technologies and protocols:

- High rate, efficient solid state amplifiers capable of very high data rates over 1,000 - 10,000 km distances with ranging signal embedded;
- Very low power, data rate, and cost inter-spacecraft S-band transceivers for inexpensive spacecraft;
- Optical transceiver capable of very high data rates over 1,000 - 10,000 km distances;
- Agile, multi-beam antennas; mesh or other material flexible reflector unfurlable antennas for Ka-band and lightweight scanning phased array antenna systems;
- SEU and solar flare tolerant transponder capable of programmable wide carrier frequency range 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 system for rendezvous and collision avoidance;
- Ad-hoc, long-range spacecraft to spacecraft network protocols to set up links on demand such that each node can route data through to another node.

O1.11 Software for Space Communications Infrastructure Operations

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

The current infrastructure for NASA Space Communications provides services for near-Earth spacecraft and deep-space planetary missions. The infrastructure assets include the Deep Space Network (DSN), the Ground Network (GN), and the Space Network (SN). Recent planning for the Vision for Space Exploration (VSE) for human exploration to the moon and beyond as well as maintaining vibrant space and Earth science programs resulted in a new concept of the communications architecture. The future communications architecture will evolve from the present legacy assets and with addition of new assets.
New technology is sought to improve resource optimization and the user interface of planning and scheduling tools. The software created should have a commercialization approach with the new modules fitting into an existing or in-development planning and scheduling tool. Proposals are sought in the following three areas:

**Intelligent Assistants**

In order to automate the user's provision of requirements and refinement of the schedule, "intelligent assistant" software should manage the user interface. Assistants should streamline access and modification of requirement and schedule information. By modeling the user, this software can adjust the level of autonomy by determining what decisions should be made by the user or the automated system. Assistants should try to minimize user involvement without making decisions the user would prefer to make. The assistants should adapt to the user by learning their control preferences. This technology should apply to local/centralized and collaborative scheduling.

In a conflict-aware scheduling system (especially in a collaborative scheduling environment), conflicts are prevalent. With the concept of one big schedule from the beginning of time, real time, to the end of time, resolving conflicts become a difficult task especially since resolving conflicts in a local sense may affect the global schedule. Therefore, an intelligent assistant may provide decision support to the system or the users to assist conflict resolution. This may involve a set of rules combining with certain local/global optimization to generate a list of options for the system or users to choose from.

**Resource Optimization**

The goal of schedule optimization is to produce allocations that yield the best objectives. These may include maximizing DSN utilization, minimizing loss of desired tracking time, and optimizing project satisfaction. Each project may have their own definition of satisfaction such as maximal science data returned, maximal tracking time, best allocation of the day/week, etc. The difficulty is that we may not satisfy all of these objectives during the optimization process. Obviously, optimal solution for one objective may produce worse results for the other objectives. One possible solution is to map all of these objectives to an overall system goal. This mapping is normally non-linear. Technology needs to be developed for this non-linear mapping for scoring in addition to regular optimization approaches.

**Multiple Agents**

In an environment where all system variables can be controlled by a single controller, an optimal solution for the objective function can be achieved by finding the right set of variables. In a collaborative environment with multiple decision makers where each decision maker can only control a subset of the variables, modeling and optimization become a very complex issue. In the proposed collaborative scheduling approach, there are many users/agents that will control their own allocations with interaction with the others. How we model their interactions and define system policy so the interaction can achieve the overall system goal is an important topic. The approach for multiple decision-maker collaboration has been studied in the area of Game Theory. The applications cover many areas including economics and engineering. The major solutions include Pareto, Nash, and Stackelberg. There are many new research areas including incentive control, collaborative control, Ordinal Games, etc.

Note that intelligent assistants and multiple agents represent different points on the spectrum of automation. Current operations utilize primarily manual collaborative scheduling, intelligent assistants would enhance users ability to participate in this process and intelligent agents could more automate individual customers scheduling. Ideally, proposed intelligent assistants and distributed agents would also be able to represent customers who do not wish to expose their general preferences and constraints. A start for reference material on this subtopic may be...
The proposal should explicitly include an operations scenario of before and after the inclusion of the new technology.

Space Transportation Topic O2
Achieving space flight can be astonishing. It is an undertaking of great complexity, requiring numerous technological and engineering disciplines and a high level of organizational skill. Overcoming Earth’s gravity to achieve orbit demands collections of quality data to maintain the security required of the range. The harsh environment of space puts tight constraints on the equipment needed to perform the necessary functions. Not only is there a concern for safety but the 2004 Space Transportation Policy directive that states that the US maintains robust transportation capabilities to assure access to space. Given this backdrop, this topic is designed to address technologies to enable a safer and more reliable space transportation capability. Automated collection of range data, automated tracking and identification of objects, and instrumentation for space transportation system testing are all required. The following subtopics are required secure technologies for these capabilities.

Sub Topics:

O2.01 Automated Optical Tracking and Identification of Tumbling 3D Objects
Lead Center: KSC
Participating Center(s): AFRC, GSFC

Tracking and Identification of 3D Tumbling Objects
Develop techniques to track and construct 3-dimensional views of tumbling objects in the atmosphere or space using digital optical tracking images for a variety of missions. These views will be used to determine the objects' approximate geometric sizes and shapes. The potential application is to help track and identify debris quickly after an accident or flight anomaly. The data will be provided by sequential digital images from one or more tracking cameras, ideally operating autonomously. The goal is to track and identify between 50 to 100 objects with typical cross-sections varying from tens of square meters down to one square meter or less within several minutes after an accident. The initial investigation will determine the minimum size that can be imaged using current technology, the probability of correctly estimating an object's size and shape, the processing speed, and the means for transmitting analyzed data to the command center.

GPS or Radar-aided Autofocus
Investigate using range information from radar, GPS, or other sources, for autofocusing long-range optics systems. Optical tracking provides valuable data during aerospace operations, but large distances between the target and the optical system can lead to distortions caused by atmospheric disturbances. Range information might be useful for a computer-controlled optical focusing system to decrease this distortion. The initial investigation will determine if this approach could be useful using one or multiple cameras, how it might be implemented, and if range information could be combined with other distortion-reduction techniques.

**New Optical Tracking Systems**
Investigate innovative and unconventional ways to use optical or hyperspectral imaging systems to visualize and track vehicles during launch and landing operations. Possibilities might include, but are certainly not limited to, unmanned aerial vehicle platforms or balloons. The system must be implemented unobtrusively in a spaceport environment. The initial investigation should result in a proof-of-concept demonstration in an appropriately scaled environment.

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**O2.02 Space Transportation Propulsion System and Test Facility Requirements and Instrumentation**

**Lead Center:** SSC

**Participating Center(s):** GRC, MSFC

Ground testing of propulsion systems continues to be critical in meeting NASA's strategic goals. Relevant ground testing technologies and capabilities are crucial to the development, qualification, and acceptance process of validating cargo launch vehicles and human rated vehicles including Crew Exploration Vehicles (CEV), CEV Launch Systems, Cargo Launch Vehicle (CLV), and Lunar Surface Access Modules propulsion systems. The ability to quickly and efficiently perform system certification greatly impacts all space programs.

**Instrumentation and Sensors**
NASA's SSC is concerned with expanding its suite of non-intrusive technologies that provide information on propulsion system health, the environments produced by the plumes and the effects of plumes and constituents on facilities and the environment. Current capabilities include non-intrusive optical methods of monitoring plumes for metallic contamination from erosion and wear, measuring the radiative and acoustic energies and as well as measuring the concentrations of environmentally sensitive species. SSC also requires facility health management technologies to monitor the physical health of testing infrastructure to improve the sustainability and reliability of the test facilities and components.

- **Engine Health Monitoring:** Innovative, standalone sensors for non-intrusively measuring physical properties of rocket engine plumes. Measurements of interest include, but are not limited to species, temperature, density, velocities, combustion stability and O/F measurement.
- **Plume Environments Measurements:** Advanced instrumentation and sensors to monitor the near field and far field effects and products of exhaust plumes. Examples are the levels of acoustic energy, thermal radiation and final exhaust species that will effect the environment.
- **Facility Monitoring:** Advanced instrumentation and sensors for process monitoring in high pressure 12,000 psi and high flow rate 100 lb/sec gas and cryogenic environments. Applications include; cryogenic level sensing, fast response/high accuracy cryogenic temperature sensors. Facility response and analysis capabilities for monitoring facility structure, process systems and test article interaction. These include dynamic response, structural fatigue and pipe system health.

**Computational Modeling Tools and Methods**
Developing and verifying test facilities is complex and expensive. The wide range of pressures, flow rates, and temperatures necessary for engine testing result in complex relationships and dynamics. It is not realistic to physically test each component and the component-to-component interaction in all states before designing a system. Currently, systems must be tuned after fabrication, requiring extensive testing and verification. Tools using computational methods to accurately model and predict system performance are required that integrate simple
interfaces with detailed design and/or analysis software. SSC is interested in improving capabilities and methods to accurately predict and model the transient fluid structure interaction between cryogenic fluids and immersed components to predict the dynamic loads, frequency response of facilities.

- Plume Environments: Improved capabilities to predict and model acoustic and thermal energy produced by exhaust plumes and interaction/coupling with facilities. Exhaust constituents and far field buoyant plume modeling for environmental impact assessment.
- Component Design, Prediction and Modeling: Improved capabilities to predict and model the behavior of components (valves, check valves, chokes etc.) during the facility design process. This capability is required for modeling components in high pressure 12,000 psi, high flow 100 lb/sec cryogenic environments and must address two-phase flows.
- Process System Design, Prediction and Modeling: Improved capabilities to predict and model process systems. The capability should incorporate the previous two areas to accurately model the process systems and test articles.

**O2.03 Automated Collection and Transfer of Launch Range Surveillance/Intrusion Data**

**Lead Center:** KSC  
**Participating Center(s):** GSFC

Range surveillance is a primary focus of launch range safety and often cost and schedule drivers as well. Launch delays due to difficulty in verifying a cleared range are common and will increase as development encroaches on existing spaceports and as spaceports are built in new areas. Proposals are sought for innovative sensors, instrumentation platforms, and communication technologies which expedite range clearance by providing real-time situational awareness for range operations such as launches, hazardous processing, and recovery.

- Instrumentation platforms will provide mobile or transportable surveillance assets for broad area coverage to meet range needs. These platforms should be capable of a high degree of self-sufficiency and autonomy for unattended, long-term operations. During operations the platform must maintain stability so that instruments are not required to compensate for unique environmental characteristics surrounding the operations. Platforms may include, but are not limited to, Unpiloted Aerial Vehicles (UAV), High Altitude Airships (HAA), buoys, etc.
- Instrumentation and sensors would include but not be limited to a wide spectrum of optical, infrared, Radio Frequency (RF), and millimeter wave. These would provide for the detection, recognition, and identification of persons and objects that have intruded areas of the range that must be cleared in order to conduct safe launch operations. In addition, multiple sensors and instruments may be used, or combined through the use of neural networks and data fusion, for accurate identification, and time and position of entities.
- Centric and integrated communications schemes that adhere to widely accepted standards will enable a scalable architecture for range instrumentation that supports launch operations. Data rates and bandwidth requirements may vary greatly depending on instrumentation and sensors that are incorporated on a range. These constraints and the distributed nature of a range dictate the need to include multiple communication media such as free-space optics, Wi-Fi, and terrestrial and space-based communications links in order to transport the collected data. Novel and innovative approaches to this architecture are sought.
Coding, Modulation, and Compression Topic O1.01

Power and spectrum efficient solutions are needed for both near-Earth and deep-space science and exploration applications. Channel coding efficiency from 50% to 87%, combined with good bit-error/burst-error correction property will provide solutions to multiple missions. A high-speed, digital receiver capable of demodulating coded modulations in addition to un-coded modulations is needed for future missions. In compression, implementation of a high-speed decoder for decoding a standard embedded bit-stream offering tunable lossy compression to lossless compression is desired. Proposals are sought in the following specific areas:

**Compression**

High-speed decoder capable of decoding coded bit stream conforming to CCSDS 122.0-B-1 Image Data Compression standard (www.ccsds.org [1]) is solicited. The decoder has to provide over 640 Mbits/sec decoding for up to 16-bit image data coded in an embedded bit stream. The decoder shall not consume more than 5 watts of power at the specified speed. The implementation technology shall point to potential space-use feasibility.

**Coding**

Special emphasis is placed on a channel coding design suitable for near-Earth missions, operating at least at over 80% coding rate with an error floor lower than Bit-Error-Rate (BER) of $10^{-10}$, and at least 8-bit burst-error correction property, with encoder/decoder complexity consistent with implementations at data rates close to 1 Gbps and power consumption smaller than a few watts. The new design when compared with current CCSDS Reed-Solomon (255,223) coder at BER of $10^{-5}$ shall have over 2dB Eb/No gain. The preferred code block frame length is from 4K to 16K bits. Proposed implementation technology shall point to potential space-use feasibility.

**High-Rate Receiver**

High-rate receiver capable of decoding coded and un-coded modulation suite (8-PSK, GMSK, filtered OQPSK) specified by CCSDS 413.0-G-1 April 2003 (www.ccsds.org [1]) and 16-PSK, 16-QAM, 16-APSK with processing throughput greater than 300 Mbits/sec is desired. A desirable feature for the receiver output is 7 bits/sample that can be used as input to channel decoding algorithms based on soft-decision decoding.

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Sub Topics:

- **Precision Spacecraft Navigation and Tracking Topic O1.02**

This call for proposals is meant to serve NASA's ever-evolving set of missions, which require precise tracking of spacecraft position and velocity in order to achieve mission success. The call seeks evolutionary improvements in modularity, sustainability, cost, and performance for current space navigation concepts that support the Vision for Space Exploration. This includes Projects Constellation, Prometheus, robotic servicing, and robotic Earth and space science missions. NASA also seeks disruptive navigation concepts that might not match the modularity, sustainability, cost, and/or performance of current technologies and their near-term evolution, but have convincingly demonstrable potential to overtake the evolution of current technologies within the future development of Projects Constellation and Prometheus, and Earth and space science missions, in the 2015 - 2020 timeframes.

While the definition of "precise" depends upon the mission context, typical interplanetary scenarios have required Earth-based radiometric ranging accuracies of order 1-2m at 1 AU, Doppler to 0.03 mm/sec, and plane-of-sky
angles to 2.5 nano-radians. While some legacy applications remain at 2.3 GHz, most current tracking is being done at 8.4 GHz. Forward looking demonstrations are being planned at 32 GHz. These radiometric techniques have been complimented by optical techniques which achieve ~1.5 micro-radian angular accuracy upon target approach. The accuracy of radio-based techniques is typically limited by one's ability to calibrate the path delay through intervening media (troposphere, ionosphere) and by the phase stability of electronics in both the spacecraft and ground systems. For both media and electronics, the stability goal is to achieve Allan standard deviations of $4 \times 10^{-15}$ at 100 seconds and $1.5 \times 10^{-15}$ at $10^3$ to $10^4$ seconds while maintaining, or improving upon, current levels of reliability.

Space navigation technology concepts should support launch and return to Earth, including range safety, early orbit operations, in-space assembly, cis-lunar and interplanetary transit, lunar and planetary approach and orbit, ascent and descent from lunar and planetary surfaces, including precision landing, lunar and planetary surface operations, automated rendezvous and docking, and formation flying spacecraft forming synthetic apertures for science imaging and interferometry. NASA considers applicability to multiple operational regimes through modularity and/or missionization of common components a key element in its exploration strategy. Space navigation systems must produce accurate long-term trajectory predictions as well as definitive epoch solutions. Where applicable, proposed concepts should be interoperable with and/or leverage the resources of NASA’s space communications architecture. All navigation systems should be compatible, where applicable, to continuous or near-continuous trajectory perturbations generated by onboard spacecraft systems. All concepts must show some significant advantages over current techniques in at least one of the following areas: accuracy, cost, reliability, modularity, sustainability, or for onboard systems, mass, power, and volume.

Innovative technologies are sought in the following areas:

- Highly phase-stable RF ground systems are critical to high accuracy radiometric tracking. Present systems rely upon analog transmission over 0.5 to 10 km distances of a broadband (100 - 600 MHz) spectrum. Transmission induced phase errors could be greatly reduced by developing highly phase stable digital sampling and time tagging systems that can be placed near (~10m) to the RF feedhorn without measurably degrading the RF signal capture with spurious tones and noise. Phase stability goals are given above. The sampler should Nyquist sample the 100 - 600 MHz band with at least 8-bit resolution and be capable of digitally transmitting the resulting samples over fiber optic lines;

- The VLBI parameter estimation software used to build the radiometric reference frames used for precise tracking relies on a Square Root Information Filter that makes use of Householder transformation techniques. These solutions often take several days of CPU on a modern workstation. Block matrix techniques have the potential to optimize the interaction of the CPU and cache memory thereby greatly reducing the CPU time needed for solutions. The goal is a factor of three improvement in total solution time for problems with 7 million data points and 500,000 parameters, which include at least 5000 parameters that are active over the entire data set;

- Microwave radiometry of atmospheric emission lines (22 GHz H$_2$O, 60 GHz O$_2$) has been successful in demonstrating 1 mm level calibration of tropospheric path delay. However, the usefulness of this technique has been limited by the large mass and size of the instrument packages. Identifying/developing low mass, low cost implementations of this technique without significantly sacrificing accuracy would greatly enhance precise tracking;

- Develop low mass, (Less than 1 kg) low cost onboard radio frequency standards for generating highly phase-stable onboard radio signals which achieve Allan standard deviations of $1 \times 10^{-15}$ at 1000 seconds and drift of less than $10^{-15}$/day;

- Develop innovative tracking technologies using new wavelengths (X-ray, Infra-red, etc.), such as systems using celestial and planetary emissions and reflections (not limited to the visible spectrum) that can produce
three-dimensional absolute and relative position and velocity in regions where Earth-based GPS measurements are not available. The technologies can exploit either ground based or on-board techniques;

- Develop innovative technologies for improving the state of the art in terms of cost and performance in making spacecraft-to-spacecraft measurements, such as omni-directional range and bearing sensors and robotic-vision-based systems; and
- Develop innovative navigation algorithms and software supporting analysis, design, and mission operations that will reduce operations costs and support multiple systems in simultaneous, tightly-coupled, non-quiescent operations, such as robotic servicing and formation flying.

Sub Topics:
Communication for Space-Based Range Topic O1.03
Metric tracking of launch vehicles for range safety purposes is currently based on redundant radars, telemetry receivers, and uplink command transmitters at the launch site with additional assets deployed downrange in order to maintain line-of-sight communications with the vehicle as it passes over the horizon to orbital insertion.

The vision of space-based range architecture is to assure public safety, cut the costs of launch operations, decrease response time, and improve geographic and temporal flexibility by reducing, or eliminating, these assets. In order to achieve this, a number of advancements in tracking and telemetry are required. Some of NASA’s needs are:

**GPS/IMU Metric Tracking and Autonomous Systems**

Realization of a space-based range requires development of GPS receivers that incorporate:

- Low power consumption;
- Low mass/volume;
- Compliance with range safety standards;
- Flexible tracking loop programmability;
- Programmable output formats; and
- Operability in high G environments.

Other highly desirable GPS specific characteristics include open architecture supported by development software and the capability of being incorporated onto circuit boards designed for multiple functions.

Tactical grade IMUs are needed which can function on spin-stabilized rockets (up to 7 rps) and reliably function during sudden jerk and acceleration associated with launch and engine firings and can be coupled with GPS receivers.
Also needed are approaches to processing the outputs of navigation sensors and combining them with rule-based systems for autonomous navigation and termination decision making.

**Space-Based Telemetry**

Small, lightweight, low cost transceivers capable of establishing satellite communications links for telemetry and control during the launch and assent stages of flight are required to provide unbroken communications throughout the launch phase. These may enable use of the NASA TDRSS, or commercial communications satellites.

Techniques for multiplexing narrow bandwidth channels to permit increased bit rates and improved algorithms for ensuring smooth transition of support between communications satellites are also needed.

**GPS Attitude Determination for Launch Vehicles**

Investigate using inexpensive arrays of GPS antennas and receivers on small, expendable launch vehicles to determine the attitude angles and their rates of change as an alternative to traditional inertial measurement units.

The system should be contained entirely on the vehicle and not rely on ground-based processing. The attitude accuracy should be comparable to gyroscope-based systems and should be free of drift and gimble lock. The system must be able to maintain attitude output during periods of high dynamics and erratic flight. The attitude must be determined at a rate of least 10 Hz with minimal processing delay and must be output in a format compatible with vehicle telemetry systems.

**Sub Topics:**

- **Antenna Technology for Spacecraft and Planetary Surface Vehicles Topic O1.04**
  NASA seeks advanced antenna systems for use in spacecraft and planetary surface vehicles used in science, exploration systems, and space operations missions. Future manned missions to the Moon and Mars will have stringent communication requirements. Highly robust communication networks will be established in the vicinity of the planet to support long-term human interplanetary mission. Such networks will consist of a large number of communication links that connect the various network nodes. Some of these nodes must also maintain continuous high data rate communication links between the moon and the Earth. Great demands will be placed on these communication systems to assure crew safety, robustness in harsh environments, and high reliability for long duration manned missions.

  Areas of interest include lightweight deployable antenna systems, high-gain antenna architectures, multi-frequency and dual polarized antennas, self-orienting systems, reconfigurable antennas, novel concepts, antennas that can adapt to failed components without compromising performance and operability (e.g., smart antennas that include structural health monitoring and active control). NASA seeks to develop a lightweight scanning phased array antenna system that enables assured communication links for human interplanetary exploration.

  NASA is also interested in technologies enabling direct conversion of RF signals to digital and advanced concepts
wherein such systems are integrated with novel smart antenna concepts to allow true interoperability and reconfigurability in the sense of software radios.

Antenna systems for novel navigation concepts (e.g. pulsar beacons) as well as integrated communications and navigation architectures are desirable.

Large inflatable membrane antennas to significantly reduce stowage volume, provide high deployment reliability, and significantly reduced mass (i.e.

High efficient, miniature antennas with smaller than lambda square aperture size, to provide astronauts and robotics communications for surface to surface and surface to orbit for lunar, Mars, and planetary exploration missions. Recent new antenna research and development has shown that it is possible to design and build aperture antennas with smaller than the minimum effective apertures size of dipoles. This new class of antennas can provide higher antenna gains (> 2.5 dBi) than the dipole antenna in much smaller aperture size (i.e.

The architecture for lunar exploration as defined by the Space Communication Architecture Working Group (SCAWG) is expected to involve a layered communications and navigation network. This network may include lunar vicinity relay satellites at L1 and L2 Lagrange points as well as lunar polar orbiting satellites. The lunar proximity network must be able to access dedicated assets such as Malapert Station and eventually include human assets, such as crewed rovers, as relay nodes. Consequently there is an interest in antenna technologies that enable low cost but reliable reconfigurable and agile antennas at frequencies up to 38 GHz. Another component technology that shows high interest in the area of Earth and planet science is thin-membrane mountable T/R modules, phase shifters, beam former, control circuitry, etc. for future deployable/inflatable large-aperture phased array application. This topic seeks novel smart antenna concepts to address the aforementioned requirements.

There is also interest in space-to-surface links at 25.5 GHz and 37 GHz. The size of reflector antennas is limited by the accuracy of the reflector surface that can be achieved and maintained on-orbit. Development of special materials and structural techniques to control their environment, etc., reduces environmentally induced surface errors and increases the maximum useable reflector size. Distortions caused by thermal gradients are inherently a large scale phenomenon. The reflector surface is usually sufficiently accurate over substantially large local areas but these areas are not on the same desired parabolic surface. An array of feed elements can be designed to illuminate the reflector with a distorted spherical wave. This distortion can be used to compensate for large scale surface error introduced by thermal gradients, gravitational and other forces, and manufacturing. Topics of interest include but are not limited to: Compensating Feed System for an Antenna Reflector Surface With Large Scale Distortions; Techniques for the remote Measurement of Satellite Antenna Profile Errors; Determination of Orbiting S/C Antenna Distortion by Ground-Based Measurements; Measuring and Compensating Antenna Thermal Distortions; Reflectors Measurements and Corrections using arrays; Reflectors Distortion Measurement and Compensation Using Array Feeds.

NASA is interested in low cost phased array antennas for suborbital vehicles such as sounding rockets, balloons, UAV’s, and expendable vehicles. The frequencies of interest are S-band, Ku-band, and Ka-band. The arrays are required to be aerodynamic in shape for the sounding rockets, UAV’s, and expendable platforms. The balloon vehicles primarily communicate with TDRS and can tolerate a wide range of mechanical dimensions.

Antenna pointing techniques and technologies for Ka-band spacecraft antennas that can provide spacecraft knowledge with sub-milliradian precision (e.g.,
NASA is designing arrays of ground-based antennas to serve the telecommunications needs of future space exploration. Medium-size (12m class) antennas have been selected for receiving, and arrays of hundreds of them are expected to be required. Applications include communication with distant spacecraft; radar studies of solar system objects; radio astronomy; and perhaps other scientific uses. A significant challenge is the implementation of an array for transmitting (uplinking), which may or may not use the same antennas that are used for receiving. The uplink frequency will be in the 7.1 - 8.6 GHz band (X-band) in the near term and may be in the 31.5 - 33.0 GHz band (Ka-Band) in the future; it will likely carry digital modulation at rates from 10 kbps to 30 Mbps. An EIRP of at least 500 GW is required, and some applications contemplate an EIRP as high as 10 TW. It is also desirable to support as many as ten simultaneously-operating deep-space missions from one complex on Earth, and to have at least three geographically separated complexes so communication is possible with a given spacecraft at any time of the day. The major open questions in the uplink array design are:

- Minimizing the life-cycle cost of an array that produces a given EIRP by selecting the optimum combination of antenna size, transmitter power, and number of antennas. This becomes much more difficult if the option of using the same antenna for both uplink and downlink is considered;

- Identifying/developing low-cost, highly reliable, easily serviceable components for key systems. This could include highly integrated RF and digital signal processing electronics, including mixed-signal ASICs. It could also include low-cost, high-volume antenna manufacturing techniques. (For the receiving array, another key component is a cryogenic refrigerator for the 15 - 25K range.) Also, low-cost transmitters (including medium-power of the order of 100s of Watts) amplifiers are key;

- Phase calibration techniques are required to ensure coherent addition of the signals from individual antennas at the spacecraft. It is important to understand whether space-based techniques are required or ground-based techniques are adequate. In general, a target spacecraft in deep space cannot be used for calibration because of the long round-trip communication delay;

- Design of ultra phase-stable electronics to maintain the relative phase among antennas. These will minimize the need for continuous, extensive and/or disruptive calibrations;

- Understanding the effect of the medium (primarily the Earth's troposphere) on the coherence of the signals at the target spacecraft. Generally, turbulence in the medium tends to disrupt the coherence in a way that is time-dependent and site-dependent. A quantitative understanding of this is needed; and

- Techniques for integrating a very low-noise, cryogenically-cooled receiver with medium power (1W to 200W) transmitter. If transmitting and receiving are combined on the same antenna, the performance of each should be compromised as little as possible while maintaining low cost and high reliability.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration that will, when appropriate, deliver a demonstration unit for testing at the completion of the Phase 2 contract.

Sub Topics:
Reconfigurable/Reprogrammable Communication Systems Topic O1.05
NASA seeks novel approaches in reconfigurable, reprogrammable communication systems to enable the Vision for Space Exploration, Science, and Space Operations. Exploration of the Moon and Mars will require advancements in communication systems to manage the demands of the harsh space environment on space electronics, maintain flexibility and adaptability to changing needs and requirements, and provide flexibility and survivability due to
increased mission durations. NASA missions can have vastly different transceiver requirements and available resources depending on the science objective, operating environment, and spacecraft resources. For example, deep space missions are often power constrained; operating over large distances, and subsequently have lower data transmission rates when compared to near-Earth or near planetary satellites. These requirements and resource limitations are known prior to launch; therefore, the scalability feature can be used to maximize transceiver efficiency while minimizing resources consumed. Larger platforms such as vehicles or relay spacecraft may provide more resources but may also be expected to perform more complex functions or support multiple and simultaneous communication links to a diverse set of assets.

This subtopic seeks advancements in reconfigurable transceiver and component technology, providing flexible, reconfigurable capability while minimizing on-board resources and cost. The use of open standards within the software radio development is desirable while minimizing potential increased resources and inefficiencies. Topics of interest include the development of software defined radios or radio subsystems which demonstrate reconfigurability, flexibility, reduced power consumption of digital signal processing systems, increased performance and bandwidth, reduced software qualification cost, and error detection and mitigation techniques. Complex reconfigurable systems will provide multiple channel and simultaneous waveforms. Areas of interest can be divided as follows:

**Signal Waveforms and On-Orbit Reconfiguration**

- Multiple waveforms and multiple channel support strive to reduce radio count to reduce power consumption of the overall communication system. Tradeoffs in radio count and radio complexity are considered in the analysis. Reconfiguration for software and firmware upgrades shall provide access control, authentication, and data integrity checks for the reconfiguration process. Partial reconfigurable logic allows simultaneous operation and upload of new waveforms or functions. Upon operator or automated load detection failure, capability to provide access back to a known, reliable operational state is needed. An automated restore capability ensures the system can revert to a baseline configuration, thereby avoiding permanent communications loss due to an errant reconfiguration process. Approaches should minimize size and power consumption for deep space transceivers incorporating fault tolerant, reprogrammable digital signal processing devices.

- Implementations demonstrating the concept function, and benefits of dynamic or distributed on-board processing architectures to provide maximum reconfigurability and processing capacity are sought. A common processing system capacity for communications, science, and health monitoring is envisioned.

- Demonstration of adaptive modulation and waveform recognition techniques are desired to provide capability to reconfigure to the waveform identified based on an on-board library or enable new waveform upload to the on-board library from the ground.

**Software Architecture, Implementation, Modeling and Verification**

- Development and demonstration of low overhead, low complexity hardware and software architectures to enable software component or design reuse, or common testing standards that demonstrates cost or time savings. Emphasis on the application of open standards architecture to facilitate interoperability among different vendors to minimize the operational impact of upgrading hardware and software components.

- Methods that enable portability among reconfigurable logic hardware devices among different vendors, different device families and types of digital processing technologies.

- As the use of software and firmware increases with more flexible and portable software defined radio
technologies, methods are sought to reduce the complexity and cost to space qualify and verify software operation for use in space yet maintain or increase on-orbit reliability.

- Techniques to ensure reliable software execution and failure detection and self-correction.

- One promise of a software defined radios is software and design reuse maintained in a common repository. The cost or ability to reuse software depends on implementation, development practices, code complexity and other circumstances. This subtopic seeks the development and demonstration of software tools or tool chain methodologies to enable both design and software code reuse.

Fault Tolerance

- The use of reconfigurable logic devices in software defined radios is expected to increase in the future to provide reconfigurability and on-orbit flexibility for waveforms and applications. As the densities of these devices continue to increase and feature size decreases, the susceptibility of the electronics to single event effects also increases. Novel approaches to mitigate single event effects caused by charged particles are sought that reduces power consumption and complexity compared to traditional approaches (i.e., voting schemes and constant updates (scrubbing)).

- Techniques and implementations to provide a core waveform capability within the software defined radio in the event of failure or disruption of the primary waveform and/or system hardware. Communication loss should be detected and core or "gold" waveform automatically executed to provide control access to diagnosis system and over-the-air reload operational waveform and control software.

Radio Architectures

- Innovative solutions to provide software defined radio implementations to reduce power consumption and mass. Solutions should promote modularity and common, open interfaces.

- Software defined radio implementations that enable future hardware scalability among different mission classes (e.g., low rate deep space to moderate or high rate near planetary, or relay spacecraft). Operational characteristics range from 1's to 10's Mbps at UHF and S-band frequency bands up to 10's to 100's Mbps at X, and Ka-band frequency bands.

Component Technology

- Advancements in analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities while reducing power consumption.

- Novel techniques to advance memory densities, reduce power consumption, and improve performance in harsh environments.

- Advancements in reconfigurable logic technology including processing advancements, radiation hardened commercial technology and advancements in advanced computing such as polymorphous computing.
Extravehicular (EVA) Radios Topic O1.06
This subtopic focuses on dramatically shrinking the size of the EVA radio by selecting and using micro-machined RF components in the development of a Phase 1 circuit design which demonstrates compact high Q selective devices to propose for Phase 2 to fully fabricate and demonstrate a prototype radio incorporating the compact high Q filter technology developed and demonstrated during Phase 1. This subtopic seeks proposals to close a critical technology gap in the ability to reduce the form factor and power requirements of the EVA Radio while increasing its selectivity and performance, enabling long duration human exploration while simultaneously increasing communications reliability and crew safety.

Miniature EVA Radio

Human exploration demands versatile, lightweight, and miniaturized EVA Radios to enable surface operations and increase astronaut mobility. The size, weight, and power consumption of EVA Radios must dramatically decrease to reduce overall mission costs. These EVA Radios cannot sacrifice performance for weight, power, and form factor requirements - in fact, quite the opposite. While the form factor shrinks, the performance must increase to handle the combination of voice, data, and video needed to support the complex tasks in the next generation of manned mission scenarios.

EVA Radios based on micromachined RF components eliminate the most bulky pieces - the RF components in the diplexers, pre-selectors, and bandpass filters. For example, most high rejection diplexers for space-based radios are almost as enormous as the modern radio package itself. Micro-machined RF elements can complement space radio technology by coupling high-performance and increased reliability with reduction in size.

Besides low spatial volume, a significant mass reduction, and low-power consumption, micro-machined RF devices are also attractive to operate as high Q components to perform frequency selectivity without mass penalties. To build and design high performance, tightly coupled, low volume space radios, compact selectivity-determining devices are a critical enabler. Most high Q filters above 400MHz, such as inter-digital filters and others involving resonant cavities, tend to be wholly mechanical assemblies whose size is generally governed by their frequency and some derivative of their resonate wavelength. By applying micro-machining techniques, the same filter assemblies employing advanced 3D packaging techniques can be "folded" in the design, which is conducive to an order of magnitude improvement in utilization of EVA radio volumetric space.

New EVA Radio Capability

The intent of this subtopic is to develop, apply and demonstrate advantages of micro-machined RF component-based circuitry that proliferate the implementation of next-generation lightweight EVA radios. Areas of investigation may include electromechanically tuned filters, 3D packaged, micro-machined RF resonators, filter configurations consisting of cantilevered structures, as well as carbon nanotube waveguide assemblies. Through application of these fabrication and packaging techniques great strides will be realized in improving functionality, enhancing performance and achieving high reliability for long duration manned space missions. Miniature EVA Radio features include:

- Dramatic reduction of mass;
- Dramatic reduction in power requirements;
- High selectivity components, reducing interference and overlap;
• High reliability through Fault Tolerant design;
• Frequency agility;
• Software defined waveforms and modulation/demodulation.

Technical Approach

The design and use of circuitry using micro-machined RF components to dramatically shrink EVA Radio form factor while increasing operational performance will be supported by investigations and trade studies selecting current and near-term micro-machined RF components, culminating in a circuit design demonstrating their use to make a high Q element. Phase 2 will harness the high Q element as a model; then design an overall EVA Radio architecture compliant with Space Transportation Radio System (STRS) embracing a fault tolerant hardware design. The tradeoffs in sensitivity, selectivity, and packaging will be investigated in the Phase 2 effort.

Commercialization Plan

By providing users with a small size, low power, high performance SDR-based radio platform, the miniature EVA radio has derivative uses far beyond the scope of space exploration. The combination of micro-machined RF assemblies and 3D packaging in the miniature EVA radio has vast implications for both future space exploration and commercial wireless and mobile radio communications:

First Responders: Interoperability among Police, Fire, HazMat, Homeland Security, and Medical personnel

Military: Soldier-centric secure communications, mode switchable on-the-fly

Commercial: Cell phones, pagers, Wi-Fi/Bluetooth/UWB radio integration

Sub Topics:

Transformational Communications Technology Topic O1.07

NASA seeks revolutionary, highly innovative, "transformational" communications technologies that have the potential to enable order of magnitude performance improvements for exploration systems, science, and space operations mission applications. Research focuses on (but not limited to) the following areas:

• Innovative methods of using X-ray or radio pulsar signals for precise navigation or positioning of spacecraft. Small, low mass, reliable detectors, improvements in position accuracy, digital signal processing advances for time of arrival, drift estimation, and position estimation.

• Development of nano-scale communication devices and systems (e.g., FET arrays, nano-antennas, nano-transceivers, etc.) for nano-spacecraft applications.

• Quantum entanglement or innovative breakthroughs in quantum information physics to specifically address curious effects and critical unknowns relevant to revolutionary improvements in communicating data, information or knowledge between independent entities across space-time. Methods or techniques that
demonstrate extremely novel means of effectively packaging, storing, encrypting, and/or transferring information or knowledge.

- Breakthrough power-efficiency in communications brought about through the use of natural phenomenon, e.g., soliton pulse/wave/energy propagation.
- Innovative uses of radiofrequency spectrum, planetary atmospheres, or planetary electromagnetic properties for the breakthrough communication of data, information or knowledge directly between independent entities.
- RF Micro Electro-Mechanical Systems (MEMS) devices. Besides low spatial volume, lightweight, and low-power consumption, these devices are also attractive to operate as high Q components and perform frequency selectivity - namely, agile pre-selectors, multi-couplers, and diplexers. Selectivity, or Q, for band pass filters currently comes at an unacceptably high penalty in size and mass. For example, most high rejection diplexers for space-based radios are almost as enormous as the modern radio package itself. To build and design high performance, tightly coupled, low volume space radios, compact selectivity-determining devices are a critical enabler. Most high Q filters above 400MHz, such as inter-digital filters and others involving resonant cavities, are wholly mechanical assemblies which can be "folded" in their design and lend themselves to micro machining techniques.
- Other rich areas of investigation may lie within the area between MEMS and Micro-Machined devices, including electromechanically tuned filters, 3D micro machined RF resonators, filter configurations consisting of cantilevered structures, as well as carbon nano-tube waveguides. Develop, apply and demonstrate advantages of RF MEMS circuitry that proliferate the implementation of next-generation lightweight communications systems (e.g. extravehicular activity (EVA) radios).

Sub Topics:

Long Range Optical Telecommunications Topic O1.08
This subtopic seeks innovative technologies for long-range optical telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- Space-qualifiable, efficient (greater than 25% wall plug), lightweight, variable repetition-rate (1 - 60 MHz), tunable (± 0.1 nm) pulsed 1064 nm transmitter sources (diode-pumped fiber amplifier or bulk crystal laser/amplifier) with greater than 1 kW of peak power per pulse (over the entire pulse-repetition rate), and greater than 10 W of average power, and narrow (spectral width)
- Space-qualifiable, high-peak power (> 1.2 W), average-power (> 300 mW), operating wavelength less than 1000 nm single-mode-fiber pigtailed laser diode transmitters (includes necessary modulator; internal or external driver) with narrow spectral width (25%);
- Space-qualifiable, photon counting 1064 nm and/or 1550 nm detectors a temperature of 220 K or greater, with the gain greater than 3000, detection efficiency greater than 50%, dark rate 2 active area, > 0.2 mm in active area diameter, bandwidth greater than 500 MHz, saturation levels > 50 Mcounts/s and non-gated (continuous operation), and lifetime > 3 years at 100 Mega photons /sec continuous photon flux;
- Lightweight, compact, high precision (less than 0.1 micro-radian), high bandwidth (0-2 kHz), inertial reference sensors (angle sensors, gyros) for use onboard spacecraft;
- Novel schemes for stray-light control and sunlight mitigation, especially for large (> 5 m) ground-based optical telescopes that must operate when pointed to within a few (about 3) degrees of the Sun;
- Lightweight, high precision (one micro-radian accuracy) star-trackers for spaceflight application that can be
integrated with an optical communications terminal;

- Novel techniques and technologies that will enable very low cost, large aperture (> 5 m equivalent aperture diameter) telescopes for ground or space-borne use;

- High power ground-based, relatively low-cost diode-pumped laser technology capable of reaching 100 kW average power levels in a TEM$_{00}$ mode, for uplink to spacecraft;

- Artificial laser guide-star and beam compensation techniques capable of removing all significant atmospheric turbulence distortions (tilt and higher-order components) on an uplink laser beam;

- Novel techniques to reduce the development cost and risk of future space-borne optical communications transceivers (e.g., automatic focusing or alignment techniques); and

- Systems and technologies relating to sub-microradian pointing, acquisition, and spacecraft vibration.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware demonstration that will, when appropriate, deliver a demonstration unit for testing at the completion of the Phase 2 contract.

Sub Topics:

Long Range Space RF Telecommunications Topic O1.09

This subtopic seeks innovative technologies for long-range RF telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

- Ultra-small, low-cost, low-power, modular deep-space transceivers, transponders, and components, incorporating MMICs and Bi-CMOS circuits;

- MMIC modulators with drivers to provide large linear phase modulation (above 2.5 rad), high-data rate (10 - 200 Mbps), BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (32 GHz and 38 GHz);

- High-efficiency (> 70 %) Solid-State Power Amplifiers (SSPAs), of both medium output power (10 - 50 W) and high-output power (150 W - 1 KW), using power combining techniques and/or wide-bandgap semiconductor devices at X-band (8.4 GHz) and Ka-band (32 GHz and 38 GHz);

- Traveling Wave Tube Amplifiers (TWTAs), SSPAs, modulators, and MMICs for 26 GHz Ka-band (lunar communication);

- TWTAs operating at millimeter wave frequencies and at data rates of 10 Gbps or higher;

- Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends (MEMS-based RF switches and photonic control devices needed for use in reconfigurable antennas, phase shifters, amplifiers, oscillators, and in-flight reconfigurable filters. Frequencies of interest include S-, X-, Ka-, and V-band (60 GHz). Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.
NASA is planning a series of short and long duration human and robotic missions to explore the Moon and later Mars. The lunar and Mars surface and access network architectures will enable operational activities in which nodes are simultaneously connected to each other, to Earth, and to the Crew Exploration Vehicle (CEV) via in-space relay orbiters, and wired and wireless networks that provide the bidirectional voice, video, and data services. This subtopic is divided into the surface networks and access link domains (surface to orbiting assets).

**Surface Networks**

Exploration of lunar and planetary surfaces will require short-range, bidirectional, and robust multi-point links to provide on-demand, disruption tolerant, and autonomous interconnection among surface-based assets. Some of the nodes will be fixed (base stations and relays to orbital assets) and some will be moving (rovers and humans). The ability to meet the demanding environments presented by lunar and planetary surfaces will encompass the development and integration of a number of communications and networking technologies and protocols, including:

- Low mass/power (100's of milliwatts) transceivers for very short range interfaces with sensors and other small devices to enable communications among humans, robots, and access network terminals;
- Reconfigurable, directionally selectable, steerable, multi-frequency switched patch or multiple-in multiple-out antenna arrays for human helmets, robots, and fixed structures (e.g. habitats);
- Miniaturized planar, omni-directional, dual-polarized, self-orienting, and sector antennas for surface-to-surface communications among mobile and fixed nodes;
- Low power space rated ASICs and FPGAs for wireless network products; short (Fixed, long (up to 50km) range, wireless network terminals for extending high data rate communications over large distances;
- Integrated, autonomous tracking and navigation architectures and technologies;
- Self-healing, ad-hoc, disruption tolerant network protocols for intelligent, autonomous link management and reliable throughput.

**Access Links**

Lunar and planetary surface networks will need to seamlessly interface with communications access terminals and orbiting relays that can provide autonomous and disruption tolerant connectivity to Earth based assets. The access link communications system will encompass the development and integration of a number of communications and networking technologies and protocols:

- High rate, efficient solid state amplifiers capable of very high data rates over 1,000 - 10,000 km distances with ranging signal embedded;
- Very low power, data rate, and cost inter-spacecraft S-band transceivers for inexpensive spacecraft;
- Optical transceiver capable of very high data rates over 1,000 - 10,000 km distances;
- Agile, multi-beam antennas; mesh or other material flexible reflector unfurlable antennas for Ka-band and lightweight scanning phased array antenna systems;

- SEU and solar flare tolerant transponder capable of programmable wide carrier frequency range 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 system for rendezvous and collision avoidance;

- Ad-hoc, long-range spacecraft to spacecraft network protocols to set up links on demand such that each node can route data through to another node.

Sub Topics:
Software for Space Communications Infrastructure Operations Topic O1.11
The current infrastructure for NASA Space Communications provides services for near-Earth spacecraft and deep-space planetary missions. The infrastructure assets include the Deep Space Network (DSN), the Ground Network (GN), and the Space Network (SN). Recent planning for the Vision for Space Exploration (VSE) for human exploration to the moon and beyond as well as maintaining vibrant space and Earth science programs resulted in a new concept of the communications architecture. The future communications architecture will evolve from the present legacy assets and with addition of new assets.

New technology is sought to improve resource optimization and the user interface of planning and scheduling tools. The software created should have a commercialization approach with the new modules fitting into an existing or in-development planning and scheduling tool. Proposals are sought in the following three areas:

Intelligent Assistants
In order to automate the user's provision of requirements and refinement of the schedule, "intelligent assistant" software should manage the user interface. Assistants should streamline access and modification of requirement and schedule information. By modeling the user, this software can adjust the level of autonomy by determining what decisions should be made by the user or the automated system. Assistants should try to minimize user involvement without making decisions the user would prefer to make. The assistants should adapt to the user by learning their control preferences. This technology should apply to local/centralized and collaborative scheduling.

In a conflict-aware scheduling system (especially in a collaborative scheduling environment), conflicts are prevalent. With the concept of one big schedule from the beginning of time, real time, to the end of time, resolving conflicts become a difficult task especially since resolving conflicts in a local sense may affect the global schedule. Therefore, an intelligent assistant may provide decision support to the system or the users to assist conflict resolution. This may involve a set of rules combining with certain local/global optimization to generate a list of options for the system or users to choose from.
Resource Optimization

The goal of schedule optimization is to produce allocations that yield the best objectives. These may include maximizing DSN utilization, minimizing loss of desired tracking time, and optimizing project satisfaction. Each project may have their own definition of satisfaction such as maximal science data returned, maximal tracking time, best allocation of the day/week, etc. The difficulty is that we may not satisfy all of these objectives during the optimization process. Obviously, optimal solution for one objective may produce worse results for the other objectives. One possible solution is to map all of these objectives to an overall system goal. This mapping is normally non-linear. Technology needs to be developed for this non-linear mapping for scoring in addition to regular optimization approaches.

Multiple Agents

In an environment where all system variables can be controlled by a single controller, an optimal solution for the objective function can be achieved by finding the right set of variables. In a collaborative environment with multiple decision makers where each decision maker can only control a subset of the variables, modeling and optimization become a very complex issue. In the proposed collaborative scheduling approach, there are many users/agents that will control their own allocations with interaction with the others. How we model their interactions and define system policy so the interaction can achieve the overall system goal is an important topic. The approach for multiple decision-maker collaboration has been studied in the area of Game Theory. The applications cover many areas including economics and engineering. The major solutions include Pareto, Nash, and Stackelberg. There are many new research areas including incentive control, collaborative control, Ordinal Games, etc.

Note that intelligent assistants and multiple agents represent different points on the spectrum of automation. Current operations utilize primarily manual collaborative scheduling, intelligent assistants would enhance users' ability to participate in this process and intelligent agents could more automate individual customers scheduling. Ideally, proposed intelligent assistants and distributed agents would also be able to represent customers who do not wish to expose their general preferences and constraints. A start for reference material on this subtopic may be found at the following:

http://scp.gsfc.nasa.gov/gn/gnusersguide3.pdf [3], NASA Ground Network User's Guide, Chapter 9 Scheduling; and

The proposal should explicitly include an operations scenario of before and after the inclusion of the new technology.
Sub Topics:

Automated Optical Tracking and Identification of Tumbling 3D Objects Topic O2.01

**Tracking and Identification of 3D Tumbling Objects**

Develop techniques to track and construct 3-dimensional views of tumbling objects in the atmosphere or space using digital optical tracking images for a variety of missions. These views will be used to determine the objects' approximate geometric sizes and shapes. The potential application is to help track and identify debris quickly after an accident or flight anomaly. The data will be provided by sequential digital images from one or more tracking cameras, ideally operating autonomously. The goal is to track and identify between 50 to 100 objects with typical cross-sections varying from tens of square meters down to one square meter or less within several minutes after an accident. The initial investigation will determine the minimum size that can be imaged using current technology, the probability of correctly estimating an object's size and shape, the processing speed, and the means for transmitting analyzed data to the command center.

**GPS or Radar-aided Autofocus**

Investigate using range information from radar, GPS, or other sources, for autofocusing long-range optics systems. Optical tracking provides valuable data during aerospace operations, but large distances between the target and the optical system can lead to distortions caused by atmospheric disturbances. Range information might be useful for a computer-controlled optical focusing system to decrease this distortion. The initial investigation will determine if this approach could be useful using one or multiple cameras, how it might be implemented, and if range information could be combined with other distortion-reduction techniques.

**New Optical Tracking Systems**

Investigate innovative and unconventional ways to use optical or hyperspectral imaging systems to visualize and track vehicles during launch and landing operations. Possibilities might include, but are certainly not limited to, unmanned aerial vehicle platforms or balloons. The system must be implemented unobtrusively in a spaceport environment. The initial investigation should result in a proof-of-concept demonstration in an appropriately scaled environment.

Sub Topics:

Space Transportation Propulsion System and Test Facility Requirements and Instrumentation Topic O2.02

**Ground testing of propulsion systems continues to be critical in meeting NASA’s strategic goals. Relevant ground testing technologies and capabilities are crucial to the development, qualification, and acceptance process of validating cargo launch vehicles and human rated vehicles including Crew Exploration Vehicles (CEV), CEV Launch Systems, Cargo Launch Vehicle (CLV), and Lunar Surface Access Modules propulsion systems. The ability to quickly and efficiently perform system certification greatly impacts all space programs.**

**Instrumentation and Sensors**

NASA's SSC is concerned with expanding its suite of non-intrusive technologies that provide information on propulsion system health, the environments produced by the plumes and the effects of plumes and constituents on facilities and the environment. Current capabilities include non-intrusive optical methods of monitoring plumes for metallic contamination from erosion and wear, measuring the radiative and acoustic energies and as well as measuring the concentrations of environmentally sensitive species. SSC also requires facility health management technologies to monitor the physical health of testing infrastructure to improve the sustainability and reliability of the test facilities and components.

- **Engine Health Monitoring:** Innovative, standalone sensors for non-intrusively measuring physical properties of rocket engine plumes. Measurements of interest include, but are not limited to species, temperature, density, velocities, combustion stability and O/F measurement.
- **Plume Environments Measurements:** Advanced instrumentation and sensors to monitor the near field and far field effects and products of exhaust plumes. Examples are the levels of acoustic energy, thermal radiation and final exhaust species that will effect the environment.
- **Facility Monitoring:** Advanced instrumentation and sensors for process monitoring in high pressure 12,000 psi and high flow rate 100 lb/sec gas and cryogenic environments. Applications include; cryogenic level sensing, fast response/high accuracy cryogenic temperature sensors. Facility response and analysis...
capabilities for monitoring facility structure, process systems and test article interaction. These include
dynamic response, structural fatigue and pipe system health.

**Computational Modeling Tools and Methods**

Developing and verifying test facilities is complex and expensive. The wide range of pressures, flow rates, and
temperatures necessary for engine testing result in complex relationships and dynamics. It is not realistic to
physically test each component and the component-to-component interaction in all states before designing a
system. Currently, systems must be tuned after fabrication, requiring extensive testing and verification. Tools using
computational methods to accurately model and predict system performance are required that integrate simple
interfaces with detailed design and/or analysis software. SSC is interested in improving capabilities and methods to
accurately predict and model the transient fluid structure interaction between cryogenic fluids and immersed
components to predict the dynamic loads, frequency response of facilities.

- **Plume Environments:** Improved capabilities to predict and model acoustic and thermal energy produced by
  exhaust plumes and interaction/coupling with facilities. Exhaust constituents and far field buoyant plume
  modeling for environmental impact assessment.
- **Component Design, Prediction and Modeling:** Improved capabilities to predict and model the behavior of
  components (valves, check valves, chokes etc.) during the facility design process. This capability is
  required for modeling components in high pressure 12,000 psi, high flow 100 lb/sec cryogenic environments
  and must address two-phase flows.
- **Process System Design, Prediction and Modeling:** Improved capabilities to predict and model process
  systems. The capability should incorporate the previous two areas to accurately model the process systems
  and test articles.

Sub Topics:

Automated Collection and Transfer of Launch Range Surveillance/Intrusion Data Topic O2.03

Range surveillance is a primary focus of launch range safety and often cost and schedule drivers as well. Launch
delays due to difficulty in verifying a cleared range are common and will increase as development encroaches on
existing spaceports and as spaceports are built in new areas. Proposals are sought for innovative sensors,
instrumentation platforms, and communication technologies which expedite range clearance by providing real-time
situational awareness for range operations such as launches, hazardous processing, and recovery.

- **Instrumentation platforms will provide mobile or transportable surveillance assets for broad area coverage
  to meet range needs. These platforms should be capable of a high degree of self-sufficiency and autonomy
  for unattended, long-term operations. During operations the platform must maintain stability so that
  instruments are not required to compensate for unique environmental characteristics surrounding the
  operations. Platforms may include, but are not limited to, Unpiloted Aerial Vehicles (UAV), High Altitude
  Airships (HAA), buoys, etc.**
- **Instrumentation and sensors would include but not be limited to a wide spectrum of optical, infrared, Radio
  Frequency (RF), and millimeter wave. These would provide for the detection, recognition, and identification
  of persons and objects that have intruded areas of the range that must be cleared in order to conduct safe
  launch operations. In addition, multiple sensors and instruments may be used, or combined through the use
  of neural networks and data fusion, for accurate identification, and time and position of entities.**
- **Centric and integrated communications schemes that adhere to widely accepted standards will enable a
  scalable architecture for range instrumentation that supports launch operations. Data rates and bandwidth
  requirements may vary greatly depending on instrumentation and sensors that are incorporated on a range.
  These constraints and the distributed nature of a range dictate the need to include multiple communication
  media such as free-space optics, Wi-Fi, and terrestrial and space-based communications links in order to
  transport the collected data. Novel and innovative approaches to this architecture are sought.**