NASA communications capabilities are based on the premise that communications shall be an enabler 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 long range optical communications (under the Science Mission Directorate), near earth and intersatellite optical communications, RF communications technologies including antennas, surface networks, reprogrammable/reconfigurable communications systems, advanced antenna technology and transmit array concepts, and communications in support of launch services are very important to the future of the exploration and science activities of NASA. Communications that enable the range safety data from sensitive instruments is imperative. The subtopics below address these technologies and support the goals of 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 application scenarios. Coding efficiency from 50% to 87% will be combined with digital modulation from 2bits/symbol/Hz up to yield-optimal solutions. In compression, tunable technique from over 10:1 compression ratio to lossless is desired. Proposals are sought in the following specific areas:

Compresssion

- Software for transcoding of compressed bit streams from CCSDS Image Data Compression recommendation to commercial JPEG2k bit stream; and

- Demonstration in either PC-based or workstation-based systems with minimal loss of quality during the transcoding process.

Coding and Coded Modulation

- A design for a set of coded modulations operating at bandwidth efficiencies from 0.5 bits/symbol/Hz to 3+ bits/symbol/Hz, in steps of approximately 0.5 bits/symbol/Hz. Each point design shall require a bit signal-to-noise ratio not higher than 1 dB above the unconstrained-input, 2-dimensional capacity of the additive white Gaussian noise (AWGN) channel. The preferred input block frame length is 4K to 16K bits.

- 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 10e-10, and encoder/decoder complexity consistent with implementations at data rates up to 1 Gbps. The new design, when compared with current CCSDS Reed-Solomon (255,223) coder at BER of 10e-5, should have over 2dB Eb/No gain. The preferred code block frame length is from 4K to 16K bits.

- High-speed implementation of the coded modulation suite with processing throughput close to 300 Mbits/sec and demonstration in test bed. The test bed shall include functions of encoding, modulation, demodulation, and decoding. The ability for the test bed to incorporate channel impairments, an over-the-air RF component, and software re-configurability, are desirable.

- RF receivers with symbol synchronizer providing soft-decision output over 8 bits/sample, as input to Maximum Likelihood Detector to provide metrics for decoding Trellis-coded-Modulation.

O1.02 Precision Navigation and Tracking

Lead Center: JPL
Participating Center(s): 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, including all development spirals of systems of systems supporting 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 timeframe of the later spirals 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 of 1.5 e-15 at 1e3 to 1e4 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.

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O1.03 Communication for Space-Based Range
Lead Center: GSFC
Participating Center(s): AFRC, KSC, MSFC

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: (a) low power consumption, (b) low mass/volume, (c) compliance with range safety standards, (d) flexible tracking loop programmability, (e) programmable output formats, and (f) 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
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 upon 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, and novel concepts such as antennas that can adapt to failed components without compromising performance and operability (e.g., smart antennas). NASA seeks to develop a lightweight, scanning, phased array antenna system that enables assured communication links for human interplanetary exploration.

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

High efficiency, 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 antenna research and development has shown that it is possible to design and build aperture antennas with smaller than the minimum effective aperture sizes of dipoles. This new class of antennas can provide higher antenna gains (>2.5 dBi) than a dipole antenna in much smaller aperture sizes ()

The architecture for lunar exploration 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 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 that 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 errors induced by thermal gradients, gravitational and other forces, and manufacturing processes. 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; 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, UAVs, and expendable platforms. The balloon vehicles primarily communicate with TDRS and can tolerate a wide range of mechanical dimensions.

Finally, antenna pointing techniques and technologies for Ka-band spacecraft antennas that can provide spacecraft knowledge with sub-milliradian precision (e.g.,

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**O1.05 Antenna Array Transmission Techniques**

**Lead Center:** JPL

**Participating Center(s):** GRC

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.

O1.06 Reconfigurable/Reprogrammable Communication Systems

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

NASA seeks novel approaches in reconfigurable, reprogrammable communication systems to enable the vision of Space, Exploration, Science, and Aeronautical Systems. Exploration of Martian and lunar environments 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 (e.g. 1’s to 10's Mbps at UHF and S-band frequency bands up to 10's to 1000's Mbps at X, and Ka-band frequency bands.) 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 solicitation seeks advancements in reconfigurable transceivers and associated component technologies. The goal of the subtopic is to provide flexible, reconfigurable communications capability while minimizing on-board resources and cost. Topics of interest include the development of software-defined radios or radio subsystems that demonstrate reconfigurability, flexibility, reduced power consumption of digital signal processing systems, increased performance and bandwidth, reduced software qualification cost, and error detection and mitigation technologies. Complex reconfigurable systems will provide multiple channel and multiple and simultaneous waveforms. Areas of interest to develop and/or demonstrate are as follows:

- Advancements in bandwidth capacity, reduced resource consumption, or adherence to standard and open hardware and software interfaces. Techniques should include fault tolerant, reliable software execution, reprogrammable digital signal processing devices;
• Reconfigurable software and firmware that provide access control, authentication, and data integrity checks of the reconfiguration process including partial reconfiguration, which allows simultaneous operation and upload of new waveforms or functions;

• Operator or automated reconfiguration, or waveform load detection failure, and the ability to provide access back to a known, reliable operational state. An automated restore capability ensures the system can revert to a baseline configuration, thereby avoiding permanent communications loss due to an errant reconfiguration process or logic upset;

• Dynamic or distributed on-board processing architectures to provide reconfigurability and processing capacity. For example, demonstrate technologies to enable a common processing system capacity for communications, science, and health monitoring;

• Adaptive modulation and waveform recognition techniques are desired to enable transceivers to exchange waveforms with other assets automatically or through ground control;

• Low overhead, low complexity hardware and software architectures to enable hardware or software component or design reuse (e.g., software portability) to demonstrate cost or time savings. Emphasis is on the application of open standard architectures to facilitate interoperability among different vendors and to minimize the operational impact of upgrading hardware and software components;

• Software tools or tool chain methodologies that enable both design and software modeling and code reuse, and advancements in optimized code generation for digital signal processing systems;

• 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 size decreases, the susceptibility of the electronics to single event effects also increases. Novel approaches are sought to mitigate single event effects in reconfigurable logic caused by charged particles, thereby improving reliability. New methods may show advancements in reduced cost, power consumption, or complexity compared to traditional approaches (i.e., voting schemes and constant updates (e.g., scrubbing)).

• Techniques and implementations to provide a core 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 capability (e.g., "gold" waveform code) is automatically executed to provide access control and restore operation;

• Innovative solutions to software-defined radio implementations that reduce power consumption and mass. Solutions should enable future hardware scalability among different mission classes (e.g., low-rate, deep space to moderate or high-rate near planetary, or relay spacecraft) and should promote modularity and common, open interfaces; and

• In component technology, advancements in analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities; novel techniques to increase memory densities; and advancements in processing and reconfigurable logic technology, each reducing power consumption and improving performance in harsh environments.

O1.07 Extravehicular (EVA) Radios

Lead Center: JSC
Participating Center(s): GRC

Human exploration of the Martian environment demands radio technology that tolerates extreme conditions.
harsh environment of the Martian atmosphere contains not only increased radiation, which is damaging to semiconductors, but also dust and ionic storms, which are disruptive to communications. Frequency agility will be necessary during periods of disruption due to these storms. Small volume and low mass are always sought for any space mission; they are critical for systems embedded in EVA spacesuits, which seek to enhance the astronaut’s mobility on the planet’s surface.

The focus of this activity is to develop radio methodologies that ensure increased reliability and fault-tolerance in the processor electronics and performance of EVA radios for human interplanetary missions. Exploring unknown worlds with unforeseeable threats is understandably stressful for the most intrepid astronaut. By providing a system that is even less likely to fail and easier to use, this can be mitigated. In a human exploration mission, loss of communications is not merely inconvenient; it can be deadly.

The radio systems design must reflect the very special human factors requirements imposed by the mission and the protective spacesuit. While these latter provide a pressurized atmosphere, temperature control, protection from micrometeoroids, communications, and a myriad of other functions essential to the survival of an astronaut, the best designs add bulk and inhibit natural movements. EVA radio systems must be designed to be easily operable in any circumstance.

This solicitation seeks to develop an EVA radio that notionally consists of limited front-end complexity hardware combined with a signal processing back end while minimizing traditional radio analog system components in order to maintain waveform flexibility and reconfigurability. The communication bands of interest are the space allocations from UHF to Ka; the precise band used will be dictated by bandwidth needs and the specific application. The radio should support multiple bandwidths of data transmission to support telemetry, voice, and video, and should have automatic adaptive techniques to handle changing propagation and interference. The radio should have an upper mass limit of 300g, a peak transmission power of 5W, and a receive mode which consumes no more than 10 mW.

Additionally, this radio must be configurable for many applications, with a goal of reducing radio inventory management. Ka-band is the most appropriate for high data rate video links, while UHF bands can be used for low-rate telemetry and voice applications. Operational scenarios will dictate the exact requirements, but it is envisioned that EVA radios will need to transmit both audio and video to surface rovers, landers, and habitats. An EVA-Ka proximity link will be needed to track the rover should it travel outside the astronaut’s field of view. Astronauts will need to communicate with each other while performing maintenance or service tasks either on the ground or in orbit, so an EVA-to-EVA video link will be needed. It is possible that the EVA radio will need the capability to relay communications through a satellite to maintain constant contact with landers, habitats, or astronauts that are obscured or whose signals are otherwise blocked.

Ideally, one radio type will be suitable for many applications, without extensive configuration efforts, through the use of automatic self-configuration or adaptation to the application environment. It is intended that the dual goals of flexibility and survivability can be met with a modular architecture and operational paradigm. New and innovative solutions are sought that provide provable performance and survivability improvements.

The radio should underscore design of both hardware and software for failure tolerance and slow and soft degradation upon component or gate failure. Operation should be maintained following any single point failure in a discrete component or logic gate, even if in diminished capacity. Handling multiple failures with degradation is preferred. Methods that address space hardening of critical components are envisioned. Designs should also consider fallback schemes where the goal is to maintain communications even at the cost of quality, bandwidth, or...
Phase 1: The Phase 1 proposal should address the technical challenges posed by the design considerations enumerated above. During the Phase 1 effort, the EVA radio requirements definition, the initial design, and the method of testing the EVA radio will be developed. Because testing needs to include both ground testing and space testing, the proposal should address both of these elements as well as the proposed migration path between the two. Deliverables should include a prototype simulation of the design demonstrating the EVA radio’s ability to reconfigure between bands/applications and a hardware prototype demonstrating some degree of fault survivability or reconfiguration.

Phase 2: During Phase 2, prototype integrated hardware and software comprising the EVA radio will be developed, finalized, and tested based on the designs developed in Phase 1. Design changes will be finalized in this phase as a result of testing according to the guidelines developed in Phase 1.

Phase 3: EVA radios suitable for early lunar missions will be fabricated, tested, and demonstrated according to the testing guidelines developed in Phase 1 and the prototypes fabricated in Phase 2.

Commercialization: Fire, police, and other civil and law enforcement agencies would benefit from radios that could be reconfigured on-the-fly to interoperate with each other. Currently, police and fire officials must usually be routed through a central hub and precious time is lost in the attempt to communicate between agencies. Major disasters have shown a need for a universal communication system that is adaptable.

O1.08 Transformational Communications Technology

Lead Center: GRC

Participating Center(s): JSC

NASA seeks revolutionary, highly innovative, “transformational” communications and navigational technologies to potentially enable breakthrough performance improvements for science, exploration systems, and space operations mission applications. Research focuses on (but is not limited to) the following areas:

- Use of 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 (e.g., quantum key distribution), and/or transferring information or knowledge in space-to-space or space-to-ground links;

- 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;

• RF Micro Electro-Mechanical Systems (MEMS) devices. MEMS devices have low spatial volume, are lightweight, and have low-power consumption, making them attractive to operate as high Q components and perform frequency selectivity (i.e., 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. At present, most high rejection diplexers for space-based radios are quite large. 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; and

• Other areas of investigation to consider 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. Development of RF MEMS circuitry that applies and demonstrates significant advantages that proliferate the implementation of next-generation lightweight communications systems.

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 states that the US maintain a 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. Paramount to obtaining these capabilities is the development of the technologies identified in the following subtopics.

Sub Topics:

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

Lead Center: KSC
Participating Center(s): GSFC

Automated Optical Tracking

Develop a fully automated optical tracking system using data from multiple tracking stations located in and around the spaceport to provide accurate real-time trajectory and range data on space-lift vehicles for as long as possible following launch. The necessary optical tracking algorithms will be developed and modeled, with an emphasis on a robust automated tracking capability in the presence of smoke, clouds, or haze. The camera locations may be either land or sea based, or mounted on aerial vehicles, or some combination of all three. The initial investigation will determine the maximum downrange tracking distance, the tracking errors as a function of downrange distance, the processing speed, and the means for transmitting analyzed data to the command center.
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.

O2.02 Space Transportation Test Requirements and Instrumentation

Lead Center: SSC
Participating Center(s): GRC, MSFC

Ground testing of propulsion systems is a critical requirement to enable NASA's New Vision for Exploration announced by President Bush. 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 Systems, and Lunar Surface Access Modules propulsion systems. The ability to quickly and efficiently perform system certification greatly impacts all space programs. While hydrocarbon engines have not been officially selected as the next generation of launch vehicle propulsion systems, it is widely agreed that a return to hydrocarbon propellants is necessary to achieve the heavy lift capability required by these programs.

Engine Plume Sensors and Modeling

Engine plume in situ remote measurements during ground testing can provide information on the engine health and the engine performance as well as concentrations of environmentally sensitive species without disturbing the engine testing. In particular, since hydrocarbon fueled rocket engine plumes contain carbon soot because of fuel-rich combustion, soot measurements and modeling are very important. Rocket plume sensors must be able to detect gas species, temperature, and velocity for hydrocarbons (kerosene), and hybrid fuels.

Innovative sensors are required for measuring flow rate, temperature, pressure, rocket engine plume constituents, and effluent gas detection. Sensors must not physically intrude into the measurement space. High accuracy (0.2%), low-millisecond to sub-millisecond response time is required. Temperature sensors must be able to measure both cryogenic and high temperature fluids under high pressure (up to 15,000 psi) and high flow rate conditions (82 ft/sec). Response time must be on the order of a few milliseconds to sub-milliseconds.

Innovative methods in phenomenology, modeling, sensors, and instrumentation for the prediction, characterization, and measurement of rocket engine combustion instability are of interest. Sensor systems should have bandwidth capabilities in excess of 100 kHz. Emphasis is on development of optical-based sensor systems that will be non-intrusive in the test article hardware or exhaust plume.
Sensors must support integration with Integrated Systems Health Management (ISHM) technologies.

**Engine Acoustic Energy Prediction and Sensing**

The high levels of acoustic energy generated by rocket engines can be destructive to both launch vehicles and ground test/launch facilities. Current acoustic energy prediction methods can only provide a rough order of magnitude estimate of the amount of acoustic energy that a rocket engine will generate. Consequently, facilities and vehicles may be unnecessarily over designed to withstand the higher predictions, adding unnecessary weight and complexity.

New and innovative acoustic measurement techniques and sensors are necessary to accurately measure and predict the rocket plume acoustic environment. Current methods of predicting far-field and near-field acoustic levels produced by rocket engines rely on empirical models and require numerous physical measurements. New and innovative acoustic prediction methods are required that can accurately predict the acoustic levels a priori or using fewer measurements. New, innovative techniques based on energy density measurements rather than pressure measurements show promise as replacements for the older models.

**Computational and Modeling Tools and Methods**

The wide range of pressures, flow rates, and temperatures associated with rocket propulsion systems result in complex dynamics. It is not realistic to physically test each component and the component-to-component interaction in all states before designing a system. Consequently, systems must be tuned after fabrication, requiring extensive testing and often component redesign. Tools and methods are necessary that will allow the use of computational methods to accurately model and predict system performance.

Development of tools that integrate simple operator interfaces with detailed design and/or analysis software for modeling and enhancing the flow performance of flow system components such as valves, check valves, pressure regulators, flow meters, cavitating venturis, and propellant run tanks. In addition, new and improved methods to accurately model the transient interaction between cryogenic fluid flow and immersed sensors that predict the dynamic load on the sensors, frequency spectrum, heat transfer, and effect on the flow field are needed.

**Propulsion System Exhaust Plume Flow Field Definition and Associated Plume Induced Environments (PIE)**

An accurate definition of a propulsion system exhaust plume flow field and its associated PIE are required to support the design efforts necessary to safely and optimally accomplish many phases of any space flight mission from sea level or simulated altitude testing of a propulsion system to landing on and returning from the Moon or Mars. Accurately defined PIE result in increased safety, optimized design, and minimized costs associated with:

- Propulsion system and/or component testing of both the test article and test facility;
- Launch vehicle and associated launch facility during liftoff from the Earth, Moon, or Mars;
- Launch vehicle during the ascent portion of flight including staging, effects of separation motors, and
associated pitch maneuvers;

- Effects of orbital maneuverings systems (including contamination) on associated vehicles and/or payloads and their contribution to space environments;

- Vehicles intended to land on and return from the surface of the Moon or Mars; and

- Effects of a vehicle propulsion system on the surfaces of the Moon and Mars including the contaminations of those surfaces by plume constituents and associated propulsion system constituents.

In general, the current plume technology used to define a propulsion system exhaust plume flow field and its associated plume induced environments is far superior to that used in support of the original Space Shuttle design. However, further improvements of this technology are required:

- To reduce conservatism, in the current technology, allowing greater optimization of any vehicle and/or payload design while keeping in mind crew safety through all mission phases; and

- To support the efforts to fill current critical technology gaps (below). PIE areas of particular interest include: single engine and multi-engine plume flow field definition for all phases of any space flight mission, plume induced acoustic environments, plume induced radiative and convective ascent vehicle base heating, plume contamination, and direct and/or indirect plume impingement effects.

Current critical technology gaps in needed PIE capabilities include:

- An accurate analytical prediction tool to define convective ascent vehicle base heating for both single engine and multi-engine vehicle configurations;

- An accurate analytical prediction tool to define plume induced environments associated with advanced chemical, electrical and nuclear propulsion systems; and

- A validated, user friendly, free molecular flow model for defining plumes and plume induced environments for low density external environments that exist on orbit, as well as interplanetary and other planets.

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

Lead Center: KSC
Participating Center(s): GSFC

Range surveillance is a primary focus of launch range safety and often a cost and schedule driver. Launch delays, due to the difficulty of verifying a cleared range, are common and will increase as spaceports are developed in new areas. Proposals are sought for sensors and communications technologies that expedite range clearance such as sonobouys; high altitude airships (HAAs) and related developments for thermal and gas pressure management, power systems, propulsion systems, and flight control; UAVs; use of commercial communication satellites for data transfer over the horizon; imaging through atmosphere and self learning/neural networks for pattern recognition.
Coding, Modulation, and Compression Topic O1.01

Power and spectrum efficient solutions are needed for both near Earth and deep space application scenarios. Coding efficiency from 50% to 87% will be combined with digital modulation from 2 bits/symbol/Hz up to yield-optimal solutions. In compression, tunable technique from over 10:1 compression ratio to lossless is desired. Proposals are sought in the following specific areas:

Compression

- Software for transcoding of compressed bit streams from CCSDS Image Data Compression recommendation to commercial JPEG2k bit stream; and
- Demonstration in either PC-based or workstation-based systems with minimal loss of quality during the transcoding process.

Coding and Coded Modulation

- A design for a set of coded modulations operating at bandwidth efficiencies from 0.5 bits/symbol/Hz to 3+ bits/symbol/Hz, in steps of approximately 0.5 bits/symbol/Hz. Each point design shall require a bit signal-to-noise ratio not higher than 1 dB above the unconstrained-input, 2-dimensional capacity of the additive white Gaussian noise (AWGN) channel. The preferred input block frame length is 4K to 16K bits.
- 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 10e-10, and encoder/decoder complexity consistent with implementations at data rates up to 1 Gbps. The new design, when compared with current CCSDS Reed-Solomon (255,223) coder at BER of 10e-5, should have over 2dB Eb/No gain. The preferred code block frame length is from 4K to 16K bits.
- High-speed implementation of the coded modulation suite with processing throughput close to 300 Mbits/sec and demonstration in test bed. The test bed shall include functions of encoding, modulation, demodulation, and decoding. The ability for the test bed to incorporate channel impairments, an over-the-air RF component, and software re-configurability, are desirable.
- RF receivers with symbol synchronizer providing soft-decision output over 8 bits/sample, as input to Maximum Likelihood Detector to provide metrics for decoding Trellis-coded-Modulation.
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 of $1.5 \times 10^{-15}$ at 1e3 to 1e4 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:

Communiction 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: (a) low power consumption, (b) low mass/volume, (c) compliance with range safety standards, (d) flexible tracking loop programmability, (e) programmable output formats, and (f) 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 ascent 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 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 upon 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, and novel concepts such as antennas that can adapt to failed components without compromising performance and operability (e.g., smart antennas). NASA seeks to develop a lightweight, scanning, phased array antenna system that enables assured communication links for human interplanetary exploration.

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

  High efficiency, 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 antenna research and development has shown that it is possible to design and build aperture antennas with smaller than the minimum effective aperture sizes of dipoles. This new class of antennas can
provide higher antenna gains (>2.5 dBi) than a dipole antenna in much smaller aperture sizes.

The architecture for lunar exploration 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 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 that 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 usable 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 errors induced by thermal gradients, gravitational and other forces, and manufacturing processes. 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; 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, UAVs, and expendable platforms. The balloon vehicles primarily communicate with TDRS and can tolerate a wide range of mechanical dimensions.

Finally, antenna pointing techniques and technologies for Ka-band spacecraft antennas that can provide spacecraft knowledge with sub-milliradian precision (e.g.,

Sub Topics:
Antenna Array Transmission Techniques Topic O1.05
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 O1.06

NASA seeks novel approaches in reconfigurable, reprogrammable communication systems to enable the vision of Space, Exploration, Science, and Aeronautical Systems. Exploration of Martian and lunar environments 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 (e.g. 1’s to 10’s Mbps at UHF and S-band frequency bands up to 10’s to 1000’s Mbps at X, and Ka-band frequency bands.) 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 solicitation seeks advancements in reconfigurable transceivers and associated component technologies. The goal of the subtopic is to provide flexible, reconfigurable communications capability while minimizing on-board resources and cost. Topics of interest include the development of software-defined radios or radio subsystems that demonstrate reconfigurability, flexibility, reduced power consumption of digital signal processing systems, increased performance and bandwidth, reduced software qualification cost, and error detection and mitigation technologies. Complex reconfigurable systems will provide multiple channel and multiple and simultaneous waveforms. Areas of interest to develop and/or demonstrate are as follows:

- Advancements in bandwidth capacity, reduced resource consumption, or adherence to standard and open hardware and software interfaces. Techniques should include fault tolerant, reliable software execution, reprogrammable digital signal processing devices;

- Reconfigurable software and firmware that provide access control, authentication, and data integrity checks of the reconfiguration process including partial reconfiguration, which allows simultaneous operation and upload of new waveforms or functions;

- Operator or automated reconfiguration, or waveform load detection failure, and the ability to provide access back to a known, reliable operational state. An automated restore capability ensures the system can revert to a baseline configuration, thereby avoiding permanent communications loss due to an errant reconfiguration process or logic upset;

- Dynamic or distributed on-board processing architectures to provide reconfigurability and processing capacity. For example, demonstrate technologies to enable a common processing system capacity for communications, science, and health monitoring;

- Adaptive modulation and waveform recognition techniques are desired to enable transceivers to exchange waveforms with other assets automatically or through ground control;

- Low overhead, low complexity hardware and software architectures to enable hardware or software component or design reuse (e.g., software portability) to demonstrate cost or time savings. Emphasis is on the application of open standard architectures to facilitate interoperability among different vendors and to minimize the operational impact of upgrading hardware and software components;

- Software tools or tool chain methodologies that enable both design and software modeling and code reuse, and advancements in optimized code generation for digital signal processing systems;

- 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 continues to increase, and size decreases, the susceptibility of the electronics to single event effects also increases. Novel approaches are sought to mitigate single event effects in reconfigurable logic caused by charged particles, thereby improving reliability. New methods may show advancements in reduced cost, power consumption, or complexity compared to traditional approaches (i.e., voting schemes and constant updates {e.g., scrubbing}).

- Techniques and implementations to provide a core 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 capability (e.g., "gold" waveform code) is automatically executed to provide access control and restore operation;

- Innovative solutions to software-defined radio implementations that reduce power consumption and mass. Solutions should enable future hardware scalability among different mission classes (e.g., low-rate, deep space to moderate or high-rate near planetary, or relay spacecraft) and should promote modularity and
common, open interfaces; and

- In component technology, advancements in analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities; novel techniques to increase memory densities; and advancements in processing and reconfigurable logic technology, each reducing power consumption and improving performance in harsh environments.

Sub Topics:

Extravehicular (EVA) Radios Topic O1.07

Human exploration of the Martian environment demands radio technology that tolerates extreme conditions. The harsh environment of the Martian atmosphere contains not only increased radiation, which is damaging to semiconductors, but also dust and ionic storms, which are disruptive to communications. Frequency agility will be necessary during periods of disruption due to these storms. Small volume and low mass are always sought for any space mission; they are critical for systems embedded in EVA spacesuits, which seek to enhance the astronaut's mobility on the planet's surface.

The focus of this activity is to develop radio methodologies that ensure increased reliability and fault-tolerance in the processor electronics and performance of EVA radios for human interplanetary missions. Exploring unknown worlds with unforeseeable threats is understandably stressful for the most intrepid astronaut. By providing a system that is even less likely to fail and easier to use, this can be mitigated. In a human exploration mission, loss of communications is not merely inconvenient; it can be deadly.

The radio systems design must reflect the very special human factors requirements imposed by the mission and the protective spacesuit. While these latter provide a pressurized atmosphere, temperature control, protection from micrometeoroids, communications, and a myriad of other functions essential to the survival of an astronaut, the best designs add bulk and inhibit natural movements. EVA radio systems must be designed to be easily operable in any circumstance.

This solicitation seeks to develop an EVA radio that notionally consists of limited front-end complexity hardware combined with a signal processing back end while minimizing traditional radio analog system components in order to maintain waveform flexibility and reconfigurability. The communication bands of interest are the space allocations from UHF to Ka; the precise band used will be dictated by bandwidth needs and the specific application. The radio should support multiple bandwidths of data transmission to support telemetry, voice, and video, and should have automatic adaptive techniques to handle changing propagation and interference. The radio should have an upper mass limit of 300g, a peak transmission power of 5W, and a receive mode which consumes no more than 10 mW.

Additionally, this radio must be configurable for many applications, with a goal of reducing radio inventory management. Ka-band is the most appropriate for high data rate video links, while UHF bands can be used for low-rate telemetry and voice applications. Operational scenarios will dictate the exact requirements, but it is envisioned that EVA radios will need to transmit both audio and video to surface rovers, landers, and habitats. An EVA-Ka proximity link will be needed to track the rover should it travel outside the astronaut's field of view. Astronauts will need to communicate with each other while performing maintenance or service tasks either on the ground or in orbit, so an EVA-to-EVA video link will be needed. It is possible that the EVA radio will need the capability to relay communications through a satellite to maintain constant contact with landers, habitats, or astronauts that are obscured or whose signals are otherwise blocked.
Ideally, one radio type will be suitable for many applications, without extensive configuration efforts, through the use of automatic self-configuration or adaptation to the application environment. It is intended that the dual goals of flexibility and survivability can be met with a modular architecture and operational paradigm. New and innovative solutions are sought that provide provable performance and survivability improvements.

The radio should underscore design of both hardware and software for failure tolerance and slow and soft degradation upon component or gate failure. Operation should be maintained following any single point failure in a discrete component or logic gate, even if in diminished capacity. Handling multiple failures with degradation is preferred. Methods that address space hardening of critical components are envisioned. Designs should also consider fallback schemes where the goal is to maintain communications even at the cost of quality, bandwidth, or functionality.

Phase 1: The Phase 1 proposal should address the technical challenges posed by the design considerations enumerated above. During the Phase 1 effort, the EVA radio requirements definition, the initial design, and the method of testing the EVA radio will be developed. Because testing needs to include both ground testing and space testing, the proposal should address both of these elements as well as the proposed migration path between the two. Deliverables should include a prototype simulation of the design demonstrating the EVA radio’s ability to reconfigure between bands/applications and a hardware prototype demonstrating some degree of fault survivability or reconfiguration.

Phase 2: During Phase 2, prototype integrated hardware and software comprising the EVA radio will be developed, finalized, and tested based on the designs developed in Phase 1. Design changes will be finalized in this phase as a result of testing according to the guidelines developed in Phase 1.

Phase 3: EVA radios suitable for early lunar missions will be fabricated, tested, and demonstrated according to the testing guidelines developed in Phase 1 and the prototypes fabricated in Phase 2.

Commercialization: Fire, police, and other civil and law enforcement agencies would benefit from radios that could be reconfigured on-the-fly to interoperate with each other. Currently, police and fire officials must usually be routed through a central hub and precious time is lost in the attempt to communicate between agencies. Major disasters have shown a need for a universal communication system that is adaptable.

Sub Topics:

Transformational Communications Technology Topic O1.08

NASA seeks revolutionary, highly innovative, "transformational" communications and navigational technologies to potentially enable breakthrough performance improvements for science, exploration systems, and space operations mission applications. Research focuses on (but is not limited to) the following areas:
• Use of 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 (e.g., quantum key distribution), and/or transferring information or knowledge in space-to-space or space-to-ground links;

• 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;

• RF Micro Electro-Mechanical Systems (MEMS) devices. MEMS devices have low spatial volume, are lightweight, and have low-power consumption, making them attractive to operate as high Q components and perform frequency selectivity (i.e., 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. At present, most high rejection diplexers for space-based radios are quite large. 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; and

• Other areas of investigation to consider 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. Development of RF MEMS circuitry that applies and demonstrates significant advantages that proliferate the implementation of next-generation lightweight communications systems.

Sub Topics:

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

Automated Optical Tracking

Develop a fully automated optical tracking system using data from multiple tracking stations located in and around the spaceport to provide accurate real-time trajectory and range data on space-lift vehicles for as long as possible following launch. The necessary optical tracking algorithms will be developed and modeled, with an emphasis on a robust automated tracking capability in the presence of smoke, clouds, or haze. The camera locations may be either land or sea based, or mounted on aerial vehicles, or some combination of all three. The initial investigation will determine the maximum downrange tracking distance, the tracking errors as a function of downrange distance, the processing speed, and the means for transmitting analyzed data to the command center.

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.

Sub Topics:
Space Transportation Test Requirements and Instrumentation Topic O2.02
Ground testing of propulsion systems is a critical requirement to enable NASA's New Vision for Exploration announced by President Bush. 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 Systems, and Lunar Surface Access Modules propulsion systems. The ability to quickly and efficiently perform system certification greatly impacts all space programs. While hydrocarbon engines have not been officially selected as the next generation of launch vehicle propulsion systems, it is widely agreed that a return to hydrocarbon propellants is necessary to achieve the heavy lift capability required by these programs.

Engine Plume Sensors and Modeling

Engine plume *in situ* remote measurements during ground testing can provide information on the engine health and the engine performance as well as concentrations of environmentally sensitive species without disturbing the engine testing. In particular, since hydrocarbon fueled rocket engine plumes contain carbon soot because of fuel-rich combustion, soot measurements and modeling are very important. Rocket plume sensors must be able to detect gas species, temperature, and velocity for hydrocarbons (kerosene), and hybrid fuels.

Innovative sensors are required for measuring flow rate, temperature, pressure, rocket engine plume constituents, and effluent gas detection. Sensors must not physically intrude into the measurement space. High accuracy (0.2%), low-millisecond to sub-millisecond response time is required. Temperature sensors must be able to measure both cryogenic and high temperature fluids under high pressure (up to 15,000 psi) and high flow rate conditions (82 ft/sec). Response time must be on the order of a few milliseconds to sub-milliseconds.

Innovative methods in phenomenology, modeling, sensors, and instrumentation for the prediction, characterization, and measurement of rocket engine combustion instability are of interest. Sensor systems should have bandwidth capabilities in excess of 100 kHz. Emphasis is on development of optical-based sensor systems that will be non-intrusive in the test article hardware or exhaust plume.

Sensors must support integration with Integrated Systems Health Management (ISHM) technologies.

Engine Acoustic Energy Prediction and Sensing

The high levels of acoustic energy generated by rocket engines can be destructive to both launch vehicles and ground test/launch facilities. Current acoustic energy prediction methods can only provide a rough order of magnitude estimate of the amount of acoustic energy that a rocket engine will generate. Consequently, facilities and vehicles may be unnecessarily over designed to withstand the higher predictions, adding unnecessary weight and complexity.
New and innovative acoustic measurement techniques and sensors are necessary to accurately measure and predict the rocket plume acoustic environment. Current methods of predicting far-field and near-field acoustic levels produced by rocket engines rely on empirical models and require numerous physical measurements. New and innovative acoustic prediction methods are required that can accurately predict the acoustic levels a priori or using fewer measurements. New, innovative techniques based on energy density measurements rather than pressure measurements show promise as replacements for the older models.

Computational and Modeling Tools and Methods

The wide range of pressures, flow rates, and temperatures associated with rocket propulsion systems result in complex dynamics. It is not realistic to physically test each component and the component-to-component interaction in all states before designing a system. Consequently, systems must be tuned after fabrication, requiring extensive testing and often component redesign. Tools and methods are necessary that will allow the use of computational methods to accurately model and predict system performance.

Development of tools that integrate simple operator interfaces with detailed design and/or analysis software for modeling and enhancing the flow performance of flow system components such as valves, check valves, pressure regulators, flow meters, cavitating venturis, and propellant run tanks. In addition, new and improved methods to accurately model the transient interaction between cryogenic fluid flow and immersed sensors that predict the dynamic load on the sensors, frequency spectrum, heat transfer, and effect on the flow field are needed.

Propulsion System Exhaust Plume Flow Field Definition and Associated Plume Induced Environments (PIE)

An accurate definition of a propulsion system exhaust plume flow field and its associated PIE are required to support the design efforts necessary to safely and optimally accomplish many phases of any space flight mission from sea level or simulated altitude testing of a propulsion system to landing on and returning from the Moon or Mars. Accurately defined PIE result in increased safety, optimized design, and minimized costs associated with:

- Propulsion system and/or component testing of both the test article and test facility;
- Launch vehicle and associated launch facility during liftoff from the Earth, Moon, or Mars;
- Launch vehicle during the ascent portion of flight including staging, effects of separation motors, and associated pitch maneuvers;
- Effects of orbital maneuvering systems (including contamination) on associated vehicles and/or payloads and their contribution to space environments;
- Vehicles intended to land on and return from the surface of the Moon or Mars; and
- Effects of a vehicle propulsion system on the surfaces of the Moon and Mars including the contaminations of those surfaces by plume constituents and associated propulsion system constituents.

In general, the current plume technology used to define a propulsion system exhaust plume flow field and its associated plume induced environments is far superior to that used in support of the original Space Shuttle design.
However, further improvements of this technology are required:

- To reduce conservatism, in the current technology, allowing greater optimization of any vehicle and/or payload design while keeping in mind crew safety through all mission phases; and

- To support the efforts to fill current critical technology gaps (below). PIE areas of particular interest include:
  - single engine and multi-engine plume flow field definition for all phases of any space flight mission, plume induced acoustic environments, plume induced radiative and convective ascent vehicle base heating, plume contamination, and direct and/or indirect plume impingement effects.

Current critical technology gaps in needed PIE capabilities include:

- An accurate analytical prediction tool to define convective ascent vehicle base heating for both single engine and multi-engine vehicle configurations;

- An accurate analytical prediction tool to define plume induced environments associated with advanced chemical, electrical and nuclear propulsion systems; and

- A validated, user friendly, free molecular flow model for defining plumes and plume induced environments for low density external environments that exist on orbit, as well as interplanetary and other planets.

Sub Topics:

Automated Collection and Transfer of Range Surveillance/Intrusion Data Topic O2.03
Range surveillance is a primary focus of launch range safety and often a cost and schedule driver. Launch delays, due to the difficulty of verifying a cleared range, are common and will increase as spaceports are developed in new areas. Proposals are sought for sensors and communications technologies that expedite range clearance such as sonobuoys; high altitude airships (HAAs) and related developments for thermal and gas pressure management, power systems, propulsion systems, and flight control; UAVs; use of commercial communication satellites for data transfer over the horizon; imaging through atmosphere and self learning/neural networks for pattern recognition.