NASA SBIR 2014 Phase I Solicitation

H9 Space Communications and Navigation (SCaN)

The Space Communication and Navigation Technology Area supports all NASA space missions with the development of new capabilities and services that make our missions possible. Communication links are the lifelines to our spacecraft that provide the command, telemetry, and science data transfers as well as navigation support. Advancement in communication and navigation technology will allow future missions to implement new and more capable science instruments, greatly enhance human missions beyond Earth orbit, and enable entirely new mission concepts. NASA's communication and navigation capability is based on the premise that communications shall enable and not constrain missions. Today our communication and navigation capabilities, using Radio Frequency technology, can support our spacecraft to the fringes of the solar system and beyond. As we move into the future, we are challenged to increase current data rates - 300 Mbps in LEO to about 6 Mbps at Mars - to support the anticipated 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, cognitive networks, access links, reprogrammable communications systems, advanced antenna technology, transmit array concepts, and communications in support of launch services are very important to the future of exploration and science activities of the Agency. Additionally, innovative, relevant research in the areas of positioning, navigation, and timing (PNT) are desirable. NASA's Space Communication and Navigation (SCaN) Office considers the three elements of PNT to represent distinct, constituent capabilities:

- Positioning, by which we mean accurate and precise determination of an asset's location and orientation referenced to a coordinate system.
- Navigation, by which we mean determining an asset's current and/or desired absolute or relative position and velocity state, and applying corrections to course, orientation, and velocity to attain achieve the desired state.
- Timing, by which we mean an asset's acquiring from a standard, maintaining within user-defined parameters, and transferring where required, an accurate and precise representation of time, minimize the impact of latency on overall system performance.

This year, the following technology areas are being solicited to meet increasing data throughput and accuracy needs: Optical communications, RF communications, reprogrammable communications systems and flight dynamics. Emphasis is placed on size, weight and power improvements. Innovative solutions centered on operational issues are needed in all of the aforementioned areas. All technologies developed under this topic area to be aligned with the Architecture Definition Document and technical direction as established by the NASA SCaN Office. For more details, see: (https://www.spacecomm.nasa.gov/spacecomm/).

Subtopics

H9.01 SCaN Testbed (CoNNeCT) Experiments

Lead Center: GRC

Participating Center(s): JPL

NASA has developed an on-orbit, reprogrammable, software defined radio-based (SDR) testbed facility aboard the International Space Station (ISS), to conduct a suite of experiments to advance technologies, reduce risk, and enable future mission capabilities. The Space Communications and Navigation (SCaN) Testbed Project provides SBIR recipients the opportunity to develop and field communications, navigation, and networking technologies in the laboratory and space environment based on reconfigurable, software defined radio platforms. Each SDR is compliant with the Space Telecommunications Radio System (STRS) Architecture, NASA's common architecture for SDRs. The Testbed is installed on the truss of ISS and communicates with both NASA's Space Network via Tracking Data Relay Satellite System (TDRSS) at S-band and Ka-band and direct to/from ground systems at S-band. One SDR is capable of receiving L-band at the GPS frequencies of L1, L2, and L5.

NASA seeks innovative software applications and experiments to run aboard the SCaN Testbed to demonstrate and enable future mission capability using the reconfigurable features of the software defined radios. Experiment software/firmware can run in the flight SDRs, the flight avionics computer, and on a corresponding ground SDR at the NASA Space Network, White Sands Complex. Unique experimenter ground hardware equipment may also be used. For the flight system on-orbit, experiments will consist of software/firmware provided to NASA by the SBIR recipient. This call will not provide a means to develop nor fly any new hardware in space.

Experimenters will be provided with appropriate documentation (e.g., flight SDR, avionics, ground SDR) to aid their experiment application development, and may be provided access to the ground-based and flight SDRs to prepare and conduct their experiment. Access to the ground and flight system will be provided on a best effort basis and will be based on their relative priority with other approved experiments. Please note that selection for award does not guarantee flight opportunities on the ISS.

Desired capabilities include, but are not limited to, the examples below:

- Cognitive applications.
- Spectrum efficient technologies.
- Multi-access communication.
- Space internetworking.
    - Disruption Tolerant Networking.
- Position, navigation and timing (PNT) technology.
- Aspects of reconfiguration.
    - Unique/efficient use of processor, FPGA, DSP resources.
    - Inter-process communications.
- Technologies/waveforms for formation flying.
- High data rate communications.
- Uplink antenna arraying technologies.
- Demonstration of mission applicability of SDR.
- RF sensing applications (science emulation).

Experimenters using ground or flight systems will be required to meet certain pre-conditions for flight including:

- Provide software/firmware deliverables (software/firmware source, executables, and models) suitable for flight.
- Document development and build environment and tools for waveform/applications.
- Provide appropriate documentation (e.g., experimenter requirements, waveform/software user's guide, ICD's) throughout the development and code delivery process.
- Software/firmware deliverables compliant to the Space Telecommunications Radio System (STRS) Architecture, Release 1.02.1 and submitted to waveform repository for reuse by other users.
- Verification of performance on ground based system prior to operation on the flight system.

Methods and tools for the development of software/firmware components that is portable across multiple platforms and standards-based approaches are preferred.

Documentation for both the SCaN Testbed system and STRS Architecture may be found at the following link:

(http://spaceflightsystems.grc.nasa.gov/SpaceOps/CoNNeCT/).

These documents will provide an overview of the SCaN Testbed flight and ground systems, ground development and test facilities, and experiment flow. Documentation providing additional detail on the flight SDRs, hardware suite, development tools, and interfaces will be made available to successful SBIR award recipients. Note that certain documentation available to SBIR award recipients is restricted by export control and available to U.S. citizens only.

For all above technologies, Phase I will provide experimenters time to develop and advance waveform/application architectures and designs along with detailed experiment plans. The subtopic will seek to leverage more mature waveform developments to reduce development risk in subsequent phases, due to the timeframe of the on-orbit Testbed. The experiment plan will show a path toward Phase II software/firmware completion, ground verification process, and delivering a software/firmware and documentation package for NASA space demonstration aboard the flight SDR. Phase II will allow experimenters to complete the waveform development and demonstrate technical feasibility and basic operation of key algorithms on SCaN Testbed ground-based SDR platforms and conduct their flight system experiment. Opportunities and plans should also be identified and summarized for potential commercialization.

Phase I Deliverables:

- Waveform/application architecture and detailed design document, including plan/approach for STRS compliance.
- Experiment Reference Design Mission Concept of Operations.
- Experiment Plan (according to provided template).
- Demonstrate simulation or model of key waveform/application functions.
- Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product. Early software/firmware application source and binary code and documentation. Source/binary code will be run on engineering models and/or SDR breadboards (at TRL-3-4).
- Plan and approach for Commercialization of the technology (part of final report).

Phase II Deliverables:

- Applicable Experiment Documents (e.g., requirements, design, management plans)
- Simulation or model of waveform application.
- Demonstration of waveform/application in the laboratory on SCaN Testbed breadboards and engineering models.
- Software/firmware application source and binary code (including test software) and documentation (waveform contribution to STRS Repository for reuse by others). Source/binary code will be run on engineering models and/or demonstrated on-orbit in flight system (at TRL-5-7) SDRs. Documentation of development tool chain and procedure to build files.
- Results of implementing the Commercialization Plan outlined in Phase I.

H9.02 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

This subtopic seeks innovative technologies for long range Interplanetary Optical Telecommunications supporting the needs of space missions where robotic explorers will visit distant bodies within the solar system and beyond. Our goals are increased data-rate capability in both directions, in conjunction with significant reductions of mass, power-consumption, and volume at the spacecraft. Proposals are sought in the following areas:

Systems and technologies relating to acquisition, tracking and sub-micro-radian pointing of the optical communications beam under typical deep-space ranges and spacecraft micro-vibration environment (TRL3 Phase I, and TRL4 Phase II).

- *Vibration Isolation and Rejection Platforms and Related Technologies* - Compact, lightweight, space qualifiable vibration isolation and rejection platforms for payloads with a mass between 3 and 20 kg that require less than 5 W of power and have a mass less than 3 kg that will attenuate an integrated spacecraft micro-vibration angular disturbance of 150 micro-radians to less than 0.5 micro-radians (1-sigma), from < 0.1 Hz to ~500 Hz (TRL3 Phase I, and TRL4 Phase II).Also, innovative low-noise, low mass, low power, DC-kHz inertial, angular, position, or rate sensors. Compact, ultra-low-power, low-mass, kHz bandwidth, tip-tilt mechanisms with sub-micro-radian pointing accuracies, angular ranges of ±5 mrad and supporting up to 50 gram payloads.
- *Laser Transmitters* - Space-qualifiable, >25% DC-to-optical (wall-plug) efficiency, 0.2 to 16ns pulse width 1550-nm laser transmitter for pulse-position modulated (PPM) data with random pulses at duty cycles of 0.3% to 6.25%, <35ps pulse rise and fall times and jitter, <25% pulse-to pulse energy variation (at a given pulse width) near transform limited spectral width, single polarization output with at least 20 dB polarization extinction ratio, amplitude extinction ratio greater than 45dB, average power of 5 to 20W, massing less than 500 g/W. Laser transmitter to feature slot-serial PPM data input at CML or AC-coupled PCEL levels and an RS-422 or USB control port. All power consumed by control electronics will be considered as part of DC-to-optical efficiency. Also of interest for the laser transmitter is robust and compact packaging with >100krad radiation tolerant electronics inherent in the design. Detailed description of approaches to achieve the stated efficiency is a must (TRL3 Phase I, TRL4 Phase II).
- *Photon Counting Near-infrared Detectors Arrays for Ground Receivers* - Readout electronics and close packed (not lens-coupled) kilo-pixel arrays sensitive to 1520 to 1650 nm wavelength range with single photon detection efficiencies greater than 90%. Single photon detection jitters less than 40 picoseconds 1-sigma, active diameter greater than 500 microns, 1 dB saturation rates of at least 10 mega-photons (detected) per pixel, false count rates of less than 1 MHz/square-mm, all at an operational temperature > 1.2K.
- *Photon Counting Near-infrared Detectors Arrays for Flight Receivers* - 64x64 or larger array with integrated read-out integrated circuit for the 1030 to 1080 nm or 1520 to 1650 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation loss rates of at least 2 mega-photons/pixel and operational temperatures above 220K and dark count rates of <10 MHz/mm. Radiation doses of at least 5 Krad (unshielded) shall result in less than 10% drop in single photon detection efficiency and less than 2X increase in dark count rate.
- *Ground-based Telescope Assembly* - Ground station telescope/photon-bucket technologies for developing effective aperture diameter of e10 meter at modest cost. Operations wavelength is monochromatic at a wavelength in the range of 1000-1600nm. Key requirements: a maximum image spot size of <20 micro-radian; capable of operation while pointing to within 5° of the Sun; and field-of-view of >50 micro-radian. Telescope shall be positioned with a two-axis gimbal capable of <50 micro-radian pointing accuracy, with dynamic error <10 micro-radian RMS while tracking after tip-tilt correction.

Research should be conducted to convincingly prove technical feasibility (proof-of-concept) during Phase I ideally through hardware development, with clear pathways to demonstrating and delivering functional hardware, meeting all objectives and specifications, in Phase II.

References:

- (http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/42091/1/11-1338.pdf)
- (http://ipnpr.jpl.nasa.gov/progress_report/42-183/183A.pdf)
- (http://ipnpr.jpl.nasa.gov/progress_report/42-185/185D.pdf)
- (http://ipnpr.jpl.nasa.gov/progress_report/42-182/182C.pdf)

H9.03 Long Range Space RF Telecommunications

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC

This subtopic is focused on development of innovative deep space long-range and near-Earth RF telecommunications technologies supporting the needs of space missions.

In the future, robotic and human exploration spacecraft with increasingly capable instruments producing large quantities of data will be visiting the moon and the planets. These spacecraft will also support long duration missions, such as to the outer planets, or extended missions with new objectives. They will possess reconfigurable avionics and communication subsystems and will be designed to require less intervention from Earth during periods of low activity. Concurrently, the downlink data rate demands from Earth science spacecraft will be increasing. The communication needs of these missions motivate higher data rate capabilities on the uplink and downlink, as well as more reliable RF and timing subsystems. Innovative long-range telecommunications technologies that maximize power efficiency, reliability, receiver capability, transmitted power, and data rate, while minimizing size, mass, and DC power consumption are required. The current state-of-the-art in long-range RF deep space telecommunications is 6 Mbps from Mars using microwave communications systems (X-Band and Ka-Band) with output power levels in the low tens of Watts and DC-to-RF efficiencies in the range of 10-25%. Due to the applicability of communication components and subsystems with science instruments such as radar, technologies that can benefit both RF communication and advanced instruments are within the scope of this subtopic.

Technologies of interest:

- Ultra-small, light-weight, low-cost, low-power, modular deep space and near-Earth transceivers, transponders, amplifiers, and components, incorporating MMICs, MEMs, and Bi-CMOS circuits.
- MMIC modulators with drivers to provide a wide range of linear phase modulation (greater than 2.5 rad), high-data rate (10-200 Mbps) BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (26 GHz, 32 GHz and 38 GHz).
- High DC-to-RF-efficiency (> 60%), low mass Solid-State Power Amplifiers (SSPAs), of both CW medium output power (10-15 W) and CW high-output power (15-35 W), using power combining and/or wide band-gap semiconductors at X-band (8.4 GHz) and Ka-band (26 GHz, 32 GHz and 38 GHz).
- Solid-state multi-function modules that can be commanded to toggle between amplifying conventional digital modulation format signals for communications to pulsed operation for synthetic aperture radar (SAR) with resolution on the order of few meters.
- Ultra low-noise amplifiers (MMICs or hybrid, uncooled) for RF front-ends (< 50 K noise temperature).
- High dynamic range (> 65 dB), data rate receivers (> 20 Mbps) supporting BPSK/QPSK modulations.
- MEMS-based integrated RF subsystems that reduce the size and mass of space transceivers and transponders. Frequencies of interest include UHF, X- and Ka-Band. Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.
- Novel approaches to mitigate RF component susceptibility to radiation and EMI effects.
- Innovative packaging techniques that can lead to small size, light weight compact SSPAs with integrated heat extraction for thermal stability and reliability.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables - Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4). Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

Phase II Deliverables - Working engineering model of proposed product, along with full report of development and measurements, including populated verification matrix from Phase I (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.

H9.04 Flight Dynamics GNC Technologies and Software

Lead Center: GSFC

Participating Center(s): GRC, JPL

NASA is investing in re-engineering its suite of tools and facilities that provide guidance, navigation, and control (GNC) services for the design, development, and operation of near-Earth and interplanetary missions. This solicitation seeks proposals that will develop ground system algorithms and software for flight dynamics GNC technologies to support engineering activities from concept development through operations and disposal. This subtopic does not target on-board algorithms or software.

This solicitation is primarily focused on NASA's needs in the following focused areas:

- Addition of advanced guidance, navigation, and control improvements to existing NASA software.
- Replacement of heritage GNC software systems that are nearing obsolescence or improvement of their maintainability.
- Interface improvements, tool modularization, APIs, workflow improvements, and cross platform interfaces to existing NASA software.
- Applications of optimal control theory to high and low thrust space flight guidance and control systems.
- Numerical methods and solvers for robust targeting, and non-linear, constrained optimization.
- Applications of cutting-edge estimation techniques to spaceflight navigation problems.
- Applications of cutting-edge guidance and control techniques to space trajectories.
- Applications of advanced dynamical theories to space mission design and analysis, in the context of unstable orbital trajectories in the vicinity of small bodies and libration points.

Proposals that could lead to the replacement of the Goddard Trajectory Determination System (GTDS), or leverage state-of-the-art capabilities already developed by NASA such as the General Mission Analysis Tool (gmatcentral.org), GPS-Inferred Positioning System and Orbit Analysis Simulation Software, (http://gipsy.jpl.nasa.gov/orms/goa/), Optimal Trajectories by Implicit Simulation (otis.grc.nasa.gov) are especially encouraged. Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals.

Technologies and software should support a broad range of spaceflight customers. Those that are focused on a particular mission's or mission set's needs are the subject of other solicitations by the relevant sponsoring organizations and should not be submitted in response here.

Phase I efforts shall demonstrate technical and cost feasibility at the TRL 3 level and provide a plan for completion of the effort in Phase II. Preliminary software, algorithms, and documentation shall be delivered to NASA for evaluation.

With the exception listed below for heritage software modifications, Phase II new technology development efforts shall deliver components at the TRL 5-6 level with mature algorithms and software components complete and preliminary integration and testing in an operational environment. For efforts that extend or improve existing NASA software tools, the TRL of the deliverable shall be consistent with the TRL of the heritage software. Note, for some existing software systems (see list above) this requires delivery at TRL 8. Final software, test plans, test results, and documentation shall be delivered to NASA.

H9.05 Advanced Celestial Navigation Techniques and Systems for Deep-Space Applications

Lead Center: GRC

Participating Center(s): GSFC

NASA is seeking proposals to develop advanced celestial navigation techniques and system in support of deep-space missions. Advances in positioning, attitude estimation, orbit determination, time and frequency keeping and dissemination and orbit determination are sought. System and sub-system concepts should support significant advances of independence from Earth supervision including the ability to operate effectively in the absence of Earth-based transmissions or transmissions from planetary relay spacecraft while minimizing spacecraft burden by requiring low power and minimal mass and volume. While system concepts that operate in the complete absence of human intervention or Earth-based transmissions are preferred, testing and verification of proposed systems performance will, necessarily, include Earth-based systems.

Operation during all phases of mission operations, including cruise phase, orbit phase and circularization phases are of interest. An application of interest is to enable open–loop (i.e., beaconless) pointing of high rate optical communications terminals to earth terminals. Methods and systems should be sufficient accuracy to support this capability; however, concepts which are capable of supporting planetary missions of any type are of interest.

Subjects appropriate for this sub-topic include, but are not limited to:

- Advanced methods and sensors for optical/IR detection of star fields (i.e., star cameras).
- Advanced methods and sensors detecting RF and x-ray pulsars.
- Methods to process celestial observations to perform Orbit Determination (OD) and precision attitude estimation.

Proposals to develop Artificial Intelligence methods (e.g., supervisory control) should identify gaps in the knowledge base that are particular to the use of advanced celestial methods, unique to the deep space navigation problem. User spacecraft impact is of significant importance and proposed solutions include assessments of mass, power, thermal impact on targeted mission spacecraft. Current and past mission spacecraft may be used as paradigms. Proposals that include re-purposing/cross-purposing of advanced sensors contemplated for future deep-space missions such as x-ray telescopes are preferred.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware and software demonstration unit or software package for NASA testing at the completion of the Phase II contract. Deliverables must include a phased testing, verification and validation plan. Plans that include graduated flight testing are preferred.