NASA SBIR 2011 Phase I Solicitation

O1 Space Communications

NASA's communications capability is based on the premise that communications shall enable and not constrain missions. Communications must be robust to support the numerous missions for space science, Earth science and exploration of the universe. Technologies such as optical communications, RF including antennas and ground based Earth stations, surface networks, cognitive networks, access links, reprogrammable communications systems, advanced antenna technology, transmit array concepts, and communications in support of launch services including space based assets are very important to the future of exploration and science activities of the Agency. Emphasis is placed on size, weight and power improvements, and even greater emphasis is placed on these attributes as small satellites (e.g., micro and nano satellite) technology matures. Communication technologies enabling acquisition of range safety data from sensitive instruments is imperative. 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 Office of Space Communications and Navigation (SCaN). For more details, see: (https:/www.spacecomm.nasa.gov/spacecomm/,
https://www.spacecomm.nasa.gov/spacecomm/programs/default.cfm,
https://www.spacecomm.nasa.gov/spacecomm/programs/technology/default.cfm,

https://www.spacecomm.nasa.gov/spacecomm/programs/technology/sbir/default.cfm). A typical approach for flight hardware would include: Phase I - Research to identify and evaluate candidate telecommunications technology applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Bench or lab-level demonstrations are desirable. Phase II - Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions. The proposal shall outline a path showing how the technology could be developed into space-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. Some of the subtopics in this topic could result in products that may be included in a future flight opportunity or on-orbit testing. Please see the following for more details:

- NASA Office of the Chief Technologist: (http://www.nasa.gov/offices/oct/home/index.html, http://www.nasa.gov/offices/oct/game_changing_technology/small_satellite_subsystem_tech/index.html, http://www.nasa.gov/offices/oct/crosscutting_capability/index.html).
- International Space Station payload opportunities: (http://www.nasa.gov/mission_pages/station/research/nlab/index.html, http://www.nasa.gov/mission_pages/station/research/experiments_category.html).

- CoNNeCT (Communications, Navigation & Networking Reconfigurable Testbed): (http://spaceflightsystems.grc.nasa.gov/SpaceOps/CoNNeCT/).

- Terrestrial analogs (Desert Rats, Haughton Field):(http://science.ksc.nasa.gov/d-rats/, http://ti.arc.nasa.gov/tech/asr/intelligent-robotics/haughton-field/).

- SMD Topic S4 for more details concerning requirements for Small Satellite flight opportunities. NOTE: Communications technologies relevant to space-based range are solicited for in Space Transportation Subtopic O2.03 - 21st Century Spaceport Ground System Technologies.

Subtopics

O1.01 Antenna Technology

Lead Center: GRC

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

NASA seeks advanced antenna systems and technologies to enable communications for future space operations, space science, Earth science and solar system exploration missions. These areas, in priority order, are:

Novel Materials for Next Generation Antennas

NASA is interested in exploiting novel materials approaches for next generation antennas. For example, "smart" materials such as shape memory polymers or ionic polymer metal composites to permit active shape control or beam correction are of interest. Artificial electromagnetic media for phase velocity control and impedance tuning to improve the efficiency and bandwidth of electrically small antennas is of interest. Emerging novel technologies such as ferroelectrics, multiferroics and spintronics concepts leading to new antenna designs are desirable.

Smart, Reconfigurable Antennas

Smart antennas, reconfigurable in frequency, polarization and radiation pattern, are of interest for space and planetary exploration missions. In particular, antenna designs and proof-of-concepts leading to the reduction of the number of antennas needed to meet the communication requirements associated with rovers, pressurized surface vehicles, habitats, etc., are highly desired. In addition to the aforementioned reconfigurability requirements, specific antenna features include multi-beam operation to support connectivity to different communication nodes on planetary surfaces, or in support of communication links for satellite relays around planetary orbits. Innovative receiver front-ends or technologies that allow for the DSP to move closer to the antenna terminal furthering the impact of the aforementioned, revolutionary "game-changing" antenna technology concepts are highly desirable.

Ground-based Uplink Antenna Array Designs

NASA is considering arrays of ground-based antennas to increase capacity and system flexibility, to reduce reliance on large antennas and high operating costs, and eliminate single point of failure of large antennas. A large number of smaller antennas arrayed together results in a scalable, evolvable system, which enables a flexible schedule and support for more simultaneous missions. 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. Arraying concepts that can enable technology standardization across each NASA network (i.e., DSN, NEN, and SN), within the framework of the newly envisioned NASA integrated network architecture, at Ka-band frequencies and above, are highly desired.

Phased Array Antennas

High performance phased array antennas, i.e., with efficiencies at least 3X that of state-of-practice MMIC-based phased arrays, are needed for high-data rate communication at Ka-Band frequencies and above as well as for remote sensing applications. Communications applications include: planetary exploration, landers, probes, rovers, extravehicular activities (EVA), suborbital vehicles, sounding rockets, balloons, unmanned aerial vehicles (UAV's), TDRSS communication, and expendable launch vehicles (ELV's). Also of interest are multi-band phased array antennas (e.g., X- and Ka-band) and RF/optical shared aperture dual use antennas, which can dynamically reconfigure active elements in order to operate in either band as required to maximize flexibility, efficiency and minimize the mass of hardware delivered to space. Phased array antennas for space-based range applications to accommodate dynamic maneuvers are also of interest. The arrays are required to be aerodynamic or conformal in shape for sounding rockets, UAV's, and expendable platforms and must be able to withstand the launch environment. Potential remote sensing applications include: radiometers, passive radar interferometer platforms, and synthetic aperture radar (SAR) platforms for planetary science.

Large Aperture Deployable Antennas

Large aperture deployable antennas with surface root-mean-square (rms) quality better than Î»/40 at Ka-Band frequencies and above, are desired. In addition, these antennas should significantly reduce stowage volume (packaging efficiencies as high as 50:1), provide high deployment reliability, and significantly reduced mass density (i.e., 2). These large Gossamer-like antennas are required to provide high-capacity communication links with low fabrication costs from deep space (Mars and beyond). Concepts addressing antenna adaptive beam correction with pointing control are also of interest.

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

Phase I Deliverables: Research to identify and evaluate candidate telecommunications technology applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Bench or lab-level demonstrations are desirable.

Phase II Deliverables: Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions. The proposal shall outline a path showing how the technology could be developed into space-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.

O1.02 Reconfigurable/Reprogrammable Communication Systems

Lead Center: GRC

Participating Center(s): AFRC, ARC, GSFC, JPL, JSC

NASA seeks novel approaches in reconfigurable, reprogrammable communication systems to enable the vision of space, exploration, science, and aeronautical flight systems. Advancements are required 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 ranging from 1's to 10's Mbps at UHF & S frequency bands while X & Ka frequency bands require 10's to 1000's of Mbps. Available mission resources also vary greatly 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, which 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 transceiver and associated component technology with a goal of providing flexible, reconfigurable communications capability while minimizing on-board resources and cost. Technological domains of interest include the development of software defined radios or radio subsystems which demonstrate reconfigurability, flexibility, reduced power consumption of digital signal processing systems, increased performance and bandwidth, reduced software qualification cost, and error detection and mitigation technologies. Complex reconfigurable systems will provide multiple channel and multiple and simultaneous waveforms. Within these domains of interest, desired proposal focus areas to develop and/or demonstrate technologies are as follows:

- Software/firmware for the management of waveform and/or functional reconfiguration during simultaneous radio operation while adhering to the Space Telecommunications Radio System (STRS) is desired.
- Methods and tools for the development of software/firmware components that are portable across multiple platforms. Standards-based approaches are preferred.
- Dynamic/distributed on-board processing architectures that are scalable and designed to operate in space environments.
- Component technology advancements in bandwidth capacity and reduced resource consumption.
- Analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities.
- Novel techniques or processes to increase memory densities.
- Novel approaches to mitigate device susceptibility to radiation effects.

STRS Architecture documentation is available at the following link:

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

The above URL also provides an overview of the Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) flight program. The reconfigurable radios developed for this system represent the state-of-the-art in technology for space flight communication systems and may be used as a reference for the focus areas above. See also subtopic O1.06 - CoNNeCT Experiments for additional information.

Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

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

Phase I Deliverables: Research to identify and evaluate candidate telecommunications technology applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration. Bench or lab-level demonstrations are desirable.

Phase II Deliverables: Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions. The proposal shall outline a path showing how the technology could be developed into space-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract.

O1.03 Game Changing Technologies

Lead Center: GRC

Participating Center(s): ARC, JSC

NASA seeks revolutionary, highly innovative, game changing communications technologies that have the potential to enable order of magnitude performance improvements for space operations, exploration systems, and/or science mission applications. Research is geared towards far-term research focused in (but not limited to) the following areas:

- Develop novel techniques for size, weight, and power (SWAP) of communications sys-tems by addressing digital processing and logic implementation tradeoffs, dynamic power management, hardware and software partitioning. Address high-speed, high resolution, low power consumption, and radiation tolerance (e.g., SiGe) to support near Earth and deep space mission environments. Investigate and demonstrate novel technologies to alleviate the demanding requirements (3- to- 5X improvement in sampling rate/resolution over state-of-the-art) on analog to digital converters (ADCs) and digital signal processors (DSPs).
- Develop technologies to evolve NASA communication networking and radio capabilities to autonomously sense and adapt to their environment, detect and repair problems and learn as they operate. Nodes will be dynamically aware of state and configuration of other nodes and adapt accordingly. Communications and navigation subsystems on future missions will interpret their situation on their own, understand their options, and select the best means to communicate or navigate.
- High-performance, multifunctional, nano-structured materials are of interest for applications in human

spaceflight and exploration. These materials (notably single wall carbon nanotubes) exhibit extraordinary mechanical, electrical, and thermal properties at the nanoscale and possess exceptionally high surface area. The development of nano-scale communication devices and systems including nano-antennas, nano-transceivers, etc. are of interest for nano-spacecraft applications.

- Quantum entanglement, quantum key distribution or innovative breakthroughs in quantum information physics. Address proposed revolutionary improvements in communicating data, information or knowledge. Methods or techniques that demonstrate extremely novel means of effectively packaging, storing, encrypting, and/or transferring information are sought. Significant development is needed in high flux single photon sources and entangled pair sources for highly efficient, free space communications.

- Small spacecraft, due to their limited surface area, are typically power constrained, limiting small spacecraft communications systems to low-bandwidth architectures. Technologies and architectures, which can exploit commercial or other terrestrial communication infrastructures to enable novel smallsat missions to enable a wider variety of space missions are desired. Address how existing communications architectures can be adapted and utilized to provide routine, low cost, high bandwidth communications capabilities for spacecraft to ground, and spacecraft to spacecraft applications.

- Ultra wide-band (UWB) technology is sought to support robotic localization of surface assets. Whether two-way ranging (time -of-flight) or time-difference of arrival, the ability to synchronize the receivers determine the localization accuracy. Efficient Media Access Control (MAC) and networking protocols are paramount to ensure power efficiency and scalability. Integrating communications and positioning in an ad hoc network can indeed enable situational awareness, keeping track of location and relative position to other astronauts, robots, and vehicles at any time through visual and/or audio cues. Because initial synchronization or signal acquisition for Impulse Radio Ultra-Wide Band (IR-UWB) using equivalent-time sampling takes a long time especially for low pulse repetition rate systems, precise timing and coherent reception demand more power consumption and complexity than non-coherent IR-UWB. To maintain clock stability, most IR-UWB systems do not power down the receivers during operation. Narrower pulse width spreads the RF energy over a wider bandwidth but generation of precise low jitter (
- Develop methods for use of neutrinos for communications, timing, and ranging. Neutrinos are small, near light speed particles with no electric charge. Since neutrinos travel through most matter, they could be used for extreme long-distance signaling. Detection of neutrinos currently require massive underground liquid detectors. Highly innovative concepts, methods, techniques to enable neutrino based communication, ranging, timing, are sought.

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

Phase I Deliverables: Deliverables expected at the end of Phase I include trade studies, conceptual designs, simulations, analyses, reports, etc. at TRL 1-2.

Phase II Deliverables: Demonstrate performance of technique or product through simulations and models, hardware or software prototypes. It is expected that at the end of the Phase II award period, the resulting deliverables/products will be at or above TRL 3.

O1.04 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

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

Systems and technologies relating to acquisition, tracking and sub-micro-radian pointing of the optical communications beam under typical deep-space ranges (to 40 AU) and spacecraft micro-vibration environments. Within these domains of interest, desired proposal focus areas to develop and/or demonstrate technologies are as follows:

Isolation Platforms

Compact, lightweight, space qualifiable vibration isolation platforms for payloads massing between 3 and 50 kg that require less than 15 W of power and mass less than 3 kg that will attenuate an integrated angular disturbance of 150 micro-radians from 0.01 Hz to 500 Hz to less than 0.5 micro-radians 1-sigma.

Laser Transmitters

Space-qualifiable, greater than 20% DC to optical efficiency, 0.2 to 16 nanosecond pulse-width 1550-nm laser transmitter for pulse-position modulated data with from 16 to 320 slots per symbol, less than 35 picosecond pulse rise and fall times, near transform limited spectral width, single polarization output with at least 20 dB polarization extinction ratio, amplitude extinction ratio greater than 38 dB, average power of 5 to 20 Watt, massing less than 500 grams per Watt. Also of interest for the laser transmitter are: robust and compact packaging with radiation tolerant electronics inherent in the design, and high speed electrical interface to support output of pulse position modulation encoding of sub nanosecond pulses and inputs such as Spacewire, Firewire or Gigabit Ethernet. Detailed description of approaches to achieve the stated efficiency is a must.

Photon Counting Near-Infrared Detectors Arrays for Ground Receivers

Hexagonal close packed kilo-pixel arrays sensitive to 1000 to 1650 nm wavelength range with single photon detection efficiencies greater than 60% and single photon detection jitters less than 40 picoseconds 1-sigma, active diameter greater than 15 microns/pixel, and 1 dB saturation rates of at least 10 mega-photons (detected) per pixel and dark count rates of less than 1 MHz/square-mm.

Photon Counting Near-Infrared Detectors Arrays for Flight Receivers

For the 1000 to 1600 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation rates of at least 1 mega-photons/pixel and operational temperatures above 220K and dark count rates of

Ground-Based Telescope Assembly

Telescope/photon-buckets with primary mirror diameter ~2.5-m, f-number of ~1.1 and Cassegrain focus to be used as optical communication receiver/transmitter optics at 1000-1600nm. Maximum image spot size of ~20 micro-radian, and field-of-view of a~50 micro-radian. Telescope shall be positioned with a two-axis gimbal capable of 0.25 milli-radian pointing. Desired manufacturing cost for combined telescope, gimbal and dome in quantity (tens) of approximately $2 M each.

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

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

O1.05 Long Range Space RF Telecommunications

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC

This subtopic seeks to develop innovative long-range RF telecommunications technologies supporting the needs of space missions.

Purpose (based on NASA needs) and current state-of-the-art

In the future, spacecraft with increasingly capable instruments producing large quantities of data will be visiting the moon and the planets. To enable the communication needs of these missions and maximize the data return to Earth, innovative long-range telecommunications technologies that maximize power efficiency, 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 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%.

Technologies of interest

This subtopic seeks innovative technologies in the following areas:

- Ultra-small, light-weight, low-cost, low-power, modular deep-space transceivers, transponders 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 medium output power (10 W-50 W) and high-output power (150 W-1 KW), 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).

- Utilization of nano-materials and/or other novel materials and techniques for improving the power efficiency or reducing the mass and cost of reliable vacuum electronics amplifier components (e.g., TWTAs and Klystrons).

- Ultra low-noise amplifiers (MMICs or hybrid, uncooled) for RF front-ends (
- 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.

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 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.

O1.06 CoNNeCT Experiments

Lead Center: GRC

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

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 Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT) provides SBIR recipients and through other mechanisms NASA, large business, other Government agencies, and academic partners 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 experiments to run aboard CoNNeCT 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 Space Network, White Sands Complex. Unique experimenter ground hardware equipment may also be used.

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:

- Demonstration of mission applicability of SDR.
- Aspects of reconfiguration.
    - Unique/efficient use of processor, FPGA, DSP resources.
    - Inter-process communications.
- Spectrum efficient technologies.
- Space internetworking.
    - Disruption Tolerant Networking.
- Position, navigation and timing (PNT) technology.
- Technologies/waveforms for formation flying.

- High data rate communications.
- Uplink antenna arraying technologies.
- Multi-access communication.
- RF sensing applications (science emulation).
- Cognitive applications.

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

- Provide software/firmware deliverables suitable for flight (i.e., NASA Class C flight software).
- 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 deliverable process.
- Software/firmware deliverables compliant to the Space Telecommunications Radio System (STRS) Architecture, Release 1.02.1.
- 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 CoNNeCT 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 CoNNeCT 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 controls 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. 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 CoNNeCT 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:

- Experiment Reference Design Mission Document.
- Waveform/application architecture and detailed design document, including plan/approach for STRS compliance.
- Experiment Plan.
- Demonstrate simulation or model of key waveform/application functions.
- Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4).

Phase II Deliverables:

- Experiment Requirements Document.
- Simulation or model of waveform application.
- Demonstration of waveform/application in the laboratory on CoNNeCT breadboards or engineering models.
- Software/firmware application source and binary code and documentation. Source/binary code will be run on engineering models and/or demonstrated on-orbit in flight system (at TRL-5-7) SDRs.