National Aeronautics and
Space Administration

SBIR INVESTMENTS
in OPTICAL COMMUNICATIONS TECHNOLOGY
2005 to 2014

SPACE COMMUNICATIONS AND NAVIGATION

www.nasa.gov

Cover photo: Laser Communication Relay Demonstration (LCRD).

FOREWORD

NASA's mission to pave the future of space exploration through innovations in science and technology is reflected in a balanced technology development and maturation program supported by all NASA Mission Directorates. Stimulating technology innovation through Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) programs, NASA has empowered U.S. small businesses to make significant contributions to the future of space exploration.

This technology investment portfolio highlights SBIR Phases I and II investments in optical communications technology development for the Space Operations Mission Directorate (SOMD)/Human Exploration and Operations Mission Directorate (HEOMD) from 2005 to 2014. This report summarizes technology challenges addressed and advances made by the SBIR community in optical communications technology. The goal of this document is to encourage program and project managers, stakeholders, and prime contractors to take advantage of these technology advancements to leverage their own efforts and to help facilitate infusion of technology advancements into future NASA projects. A description of NASA's SBIR Program can be found at www.sbir.nasa.gov.

SMALL BUSINESS INNOVATION RESEARCH

The Small Business Innovation Research (SBIR) Program provides opportunities for small high-technology companies to participate in Government-sponsored research and development efforts in key technology areas of interest to NASA. The SBIR Program provides significant sources of seed funding to foster technology innovation. The SBIR Phase I contracts are awarded for 6 months with funding up to $125,000; Phase II contracts are awarded for 24 months with funding up to $750,000.

HUMAN EXPLORATION

The Human Exploration and Operations Mission Directorate (HEOMD) is chartered with the development of core transportation elements, key systems, and enabling technologies required for beyond-low-Earth-orbit (LEO) human exploration that will provide the foundation for the next half-century of American leadership in space exploration.

This new space exploration era starts with increasingly challenging test missions in cislunar space, including flights to the Lagrange points, followed by human missions to near-Earth asteroids (NEAs), the Moon, the moons of Mars, and Mars as part of a sustained journey of exploration in the inner solar system. HEOMD was formed in 2011 by combining the Space Operations Mission Directorate (SOMD) and the Exploration Systems Mission Directorate (ESMD) to optimize the elements, systems, and technologies of the precursor directorates to the maximum extent possible.

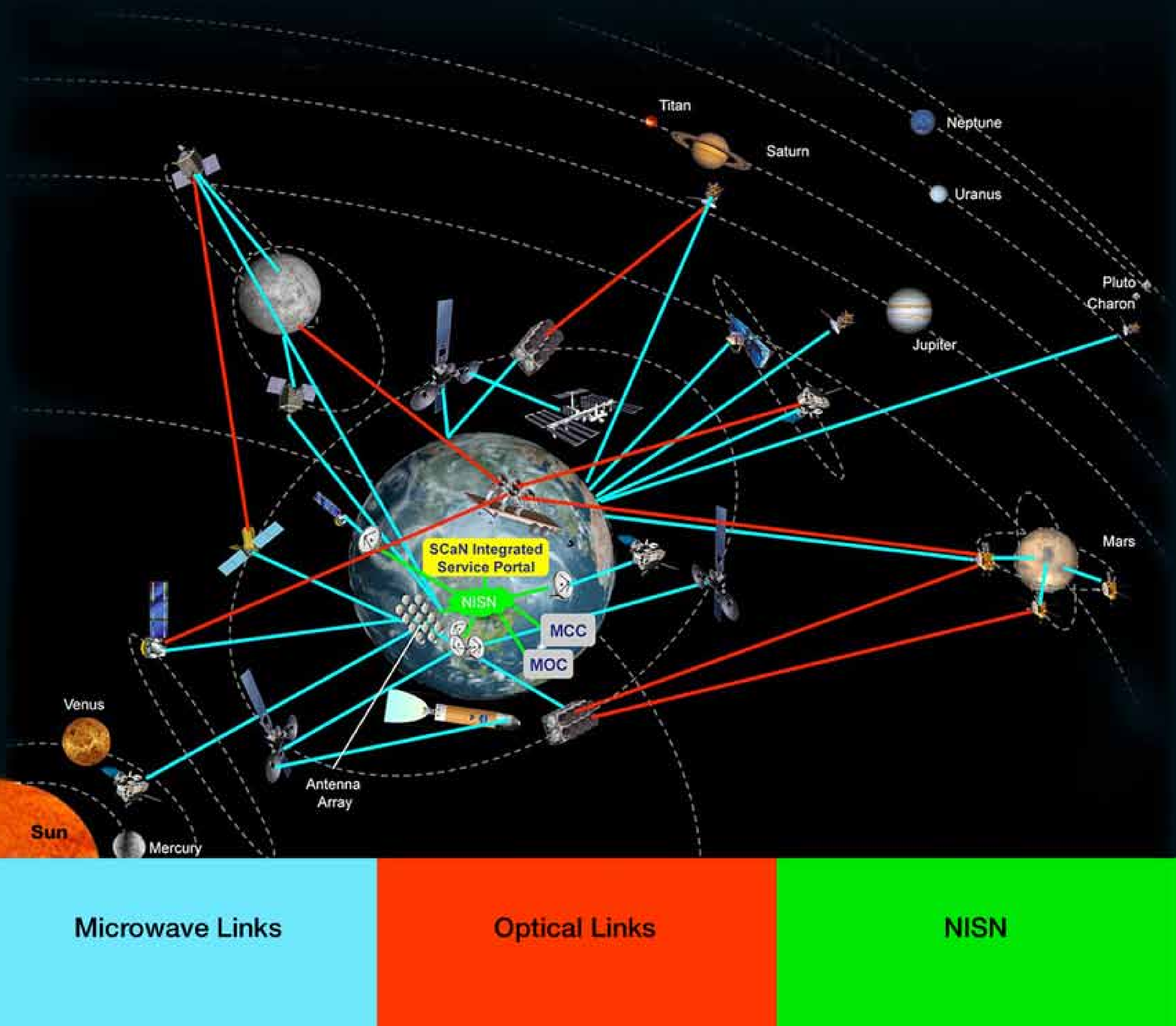
HEOMD mission goals include key technology developments in Space Communications and Navigation, Space Transportation, Human Research and Health Maintenance, Radiation Protection, Life Support and Habitation, High-Efficiency Space Power Systems, and Ground Processing/International Space Station (ISS) Utilization.

HEOMD looks forward to incorporating SBIR-developed technologies into current and future systems to contribute to the expansion of humanity across the solar system while providing continued cost-effective space access and operations for its customers, with a high standard of safety, reliability, and affordability.

AND OPERATIONS MISSION DIRECTORATE

SCaN: KEEPING THE

SCaN NOTIONAL INTEGRATED NETWORK ARCHITECTURE



UNIVERSE CONNECTED

PROGRAM AND TECHNOLOGY DEVELOPMENT OVERVIEW

The Space Communications and Navigation (SCaN) Program resides within HEOMD and is responsible for the development of technologies and capabilities to support all current and future NASA missions. The SCaN Program provides the communication, navigation, and mission science data transfer services that are vital to the successful operation of NASA space flight missions. To accomplish this, SCaN operates three networks: the Deep Space Network (DSN), the Near Earth Network (NEN), and the Space Network (SN). Combined together, the services and network assets provide capabilities that enable space exploration for over 100 NASA and non-NASA missions. SCaN also provides scheduling services to new missions through the Network Integration Management Office (NIMO) and Deep Space Network Commitment Office (DSNO).

To accomplish the above, the SCaN Program's vision is to build and maintain a scalable, integrated, and mission support infrastructure that can evolve to accommodate new and changing technologies, while providing comprehensive, robust, cost-effective, and exponentially higher data rate services to enable NASA's science and exploration missions. Today, NASA communication and navigation capabilities using radiofrequency technology can support spacecraft to the fringes of the solar system and beyond. The anticipated new missions for science and exploration of the universe are expected to challenge the current data rates of 300 Mbps in LEO and of 6 Mbps at Mars to rise significantly. The SCaN Program aims to

- Develop a SCaN network infrastructure capable of meeting both robotic and human exploration mission needs.
- Evolve infrastructure to provide the highest data rates feasible.
- Develop internationally interoperable data communications protocols for space missions.
- Offer communications and navigation infrastructure for lunar and Mars surfaces.
- Offer communications and navigation services to enable lunar and Mars human missions.

SCaN technology development interests include optical communications, advanced antenna technology and Earth stations, cognitive networks, access links, reprogrammable communications systems, spacecraft positioning, navigation, and timing (PNT), and communications in support of launch services. Innovative solutions to operational issues are needed in all of the areas. Emphasis is placed on size, weight, and power improvements. All SBIR technologies developed under the SCaN topic area are aligned with the SCaN Program technical directions.

This document catalogs SCaN SBIR investments in **optical communications technology** development from 2005 to 2014.

SBIR PHASE I AWARDS

CONTENTS

SBIR PHASE I AWARDS CONTINUED

SBIR PHASE II AWARDS

CONTENTS (CONTINUED)

OPTICAL COMMUNICATION TECHNOLOGY

Optical Ground Station

NASA 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. NASA's goals are increased duplex data-rate capability, along with significant reductions of size, weight and power (SWAP) consumption at the spacecraft. Proposals are sought in the following areas:

Systems and technologies relating to acquisition, tracking and submicroradian pointing of the optical communications beam under typical deep space ranges and spacecraft microvibration environment technology readiness level (TRL) 3 at Phase I, and TRL 4 at 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 mass less than 3 kg that will attenuate an integrated spacecraft microvibration angular disturbance of 150 microradians to less than 0.5 microradians (1-sigma), from <0.1 to ~500 Hz (TRL 3 Phase I and TRL 4 Phase II). Also, innovative low-noise, low-mass, low-power, direct current (DC) kHz inertial, angular, position, or rate sensors. Compact, ultra-low-power, low-mass, kHz bandwidth, tip-tilt mechanisms with submicroradian 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 16 ns pulse width 1550-nm laser transmitter for pulse-position-modulated (PPM) data with random pulses at duty cycles of 0.3% to 6.25%, <35 ps 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 45 dB, average power of 5 to 20 W, massing less than 500 g/W. Laser transmitter to feature slot-serial PPM data input at CML or alternating current (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 >100-krad radiation tolerant electronics inherent in the design. Detailed description of approaches to achieve the stated efficiency is a must (TRL 3 Phase I and TRL 4 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 >1.2 K.

- Photon Counting Near-Infrared Detectors Arrays for Flight Receivers—64x64 or larger array with 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 1 dB saturation loss rates of at least 2 mega-photons/pixel and operational temperatures above 220 K 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 to 1600 nm. Key requirements: a maximum image spot size of <20 microradian; capable of operation while pointing to within 5° of the Sun; and field-of-view of >50 microradian. Telescope shall be positioned with a two-axis gimbal capable of <50 microradian pointing accuracy, with dynamic error <10 microradian 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.

OPTICAL COMMUNICATION TECHNOLOGY

SBIR PHASE I AWARDS

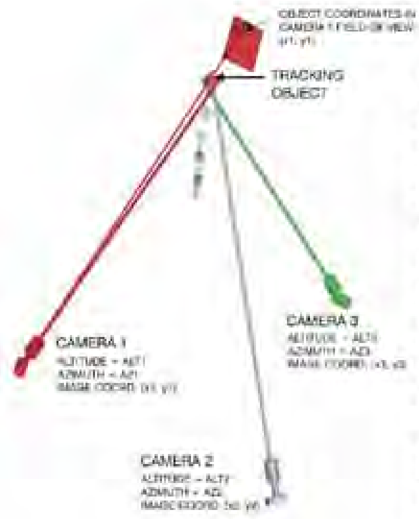
2005 TO 2014

Lunar Lasercomm Ground Terminal

ADVANCED THREE-DIMENSIONAL (3D) OBJECT IDENTIFICATION SYSTEM

OPTRA Inc.

2005 Phase I
02.01-7854



OPTICAL TRACKING OF LAUNCH VEHICLE

Each of three optical cameras continuously tracks the launch vehicle or the center of a debris field. The positions of individual objects within the camera's field-of-view (x, y) are digitally recorded and, when combined with the Altitude and Azimuth of the camera's line-of-sight (ALTo, AZo), provide accurate Altitudes and Azimuths for each object in the field-of-view.

Using image processing techniques, objects within each field-of-view are identified and tracked. Objects viewed by the three different cameras are correlated, allowing their range and accurate 3-D trajectories to be computed and tracked.

By using optical tracking (vs radar tracking), tracking stations can be smaller, less expensive, and can provide greatly improved spatial resolution.

Identification and Significance of Innovation

- There is a requirement for improved capabilities to record the initial phase of spacecraft launches. The goal is to obtain high-resolution optical data with the capability of identifying and tracking multiple objects, down to 1 m^2 in area, along the track of the launch vehicle. By using multiple cameras and object-tracking algorithms (to be developed) it will be possible to recognize objects and to determine trajectories in near real time. Knowledge of these trajectories and identification of these objects will aid greatly during search and recovery efforts.
- The significance of optical tracking systems, rather than the radar tracking systems currently in use, is that it should be possible to significantly improve the resolution with which objects are identified, while at the same time reducing the size and cost of the tracking stations. By achieving near-real-time data acquisition and interpretation, it may be possible to take immediate responsive actions in response to launch vehicle system failures.

Technical Objectives

- Develop robust algorithms for recognizing and tracking objects with three cameras and for establishing their absolute positions and velocities at moderate frame rates.
- Develop the digital camera and lens systems needed to achieve the needed spatial resolution, field-of-view, and position accuracy.
- Maximize the frame rate that can be achieved while meeting all other system requirements.

Work Plan

- Review program objectives with technical monitor.
- Review existing video data of relevant events.
- Clearly define the requirements for object recognition and tracking algorithms.
- Develop these algorithms.
- Test recognition and tracking algorithms.
- Write final report.

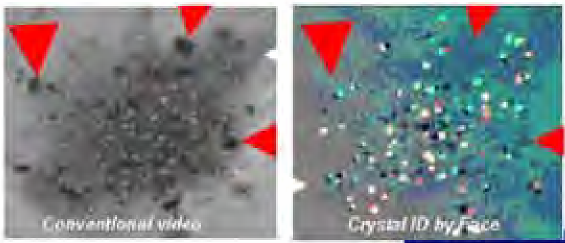
NASA Applications

- Tracking spacecraft launches
- Aiding in recovery of jettisoned components
- Providing accident analysis data
- Aiding in real-time response to launch mishaps

Non-NASA Applications

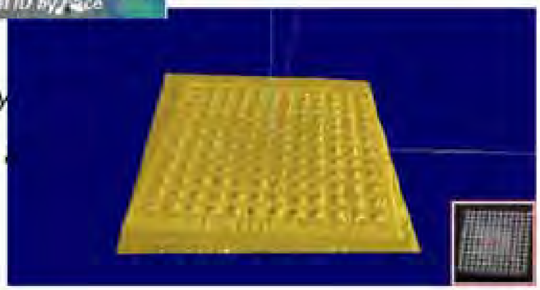
- Aircraft tracking and identification
- Surveillance

THREE-DIMENSIONAL (3D) VISUALIZATION SYSTEM FOR TRACKING AND IDENTIFICATION OF OBJECTS



Successful NASA application of 3D identification and monitoring of the growth and shape of protein crystals over time.

Commercial application of technology for measurement of 3D electronics fabrication. The application requires rapid detection of 3D shape of thousands of small hemispherical solder points.



Photon-X, Inc.

2005 Phase I
02.01-7857

Technical Objectives

The Phase I objectives are to demonstrate how Photon-X's optical-based spatial phase technology can be used to generate efficient and high-resolution 3D views of tumbling objects in space. A proof-of-concept demonstration of the underlying technology will be performed to demonstrate the applicability of the technology for this application. In Phase I, we propose to demonstrate the ability to track multiple 3D objects in a scaled version of objects in space.

Initial laboratory tests will be performed on scaled 3D tumbling models and a final proof-of-concept test will be performed on several 3D objects that will be tumbling through the field of view while being identified by shape as well as being tracked. The success will be based on successful tracking of several 3D tumbling objects through the cameras field of view.

NASA and Non-NASA Applications

Photon-X has developed a patented imaging process that can provide an efficient and accurate means to generate a high-resolution 3D image mosaic output to be used for tracking 3D tumbling objects in real time. The Photon-X technology uses a single camera that would passively allow for crisp 3D image mosaics to be constructed from flyby snapshot views generating a volumetric view of the surface area under inspection. The system could also be used as a pretactile sensor allowing for object recognition or robotic vision. The sensor has potential in many commercial applications such as 3D animation, sports motion, and machine vision.

Identification and Significance of Innovation

The Photon-X imaging technology is called spatial phase and generates a crisp 3D image mosaic using the following innovations.

- Single camera to generate 3D real-time mosaics
- Image is angle invariant to the surface area being measured
- Image is resolution and scale invariant over extended ranges
- Image is invariant to lighting changes, surface area, and textures or curvature and can detect objects better in smoke and fog
- Small in size and easily adaptable to unique configurations

The output of the 3D Visualization System for Tracking Objects has a resolution sufficient to detect many 3D objects and track the objects through space. The Photon-X technology is the first 3D technology that has the potential to be used in a space application, with its strong passive techniques coupled with a high-precision measurement in a single camera package.

DIGITAL IMAGE-BASED AUTOMATIC TRACKING CAPABILITY

OPTRA, Inc.

2005 Phase I
02.01-7865

GRAPHIC UNAVAILABLE

Identification and Significance of Innovation

The launches and landings of spacecraft are the most demanding phases of missions. During launch it is critical that the space vehicle be accurately tracked to ensure its successful insertion into orbit, and to monitor several phases of the launch sequence (liftoff, booster separation, separation from the main fuel tank, transition to orbital flight, etc.).

To date, optical tracking at NASA's Kennedy Space Center has been accomplished by manually guided tracking stations, which may carry auxiliary video cameras. This proposal describes an automated approach to optical tracking where multiple optical tracking stations can automatically track the space vehicle following launch, while at the same time providing high-resolution imagery of the space vehicle. The combined data from multiple tracking stations will allow accurate determination of vehicle trajectory and extrapolation of real-time trajectory to stay on target.

Technical Objectives

- Develop a robust tracking algorithm to generate ALT and AZ error signals; servo control each tracking mount to keep its optical axis accurately aligned with the target.
- Develop a protocol to generate real-time trajectory data based on the inputs from tracking stations.
- Design and assemble a prototype focal plane array (digital imager), optical system (telescope), and servo-controlled ALT/AZ mount to test and evaluate target acquisition and tracking algorithms.
- Determine tracking distance, errors as a function of distance, processing speed, and data delivery time to command center.

Work Plan

- Develop target acquisition algorithm(s).
- Develop automated tracking algorithm.
- Design prototype tracking system (digital camera, telescope, servo-controlled tracking mount, and PC with fast frame-grabber card).
- Determine tracking distance, errors as a function of distance, processing speed, and means for delivering analyzed data to command center.
- Test prototype system and assess results.
- Write final report.

NASA Applications

Tracking spacecraft launches with high-resolution imagery

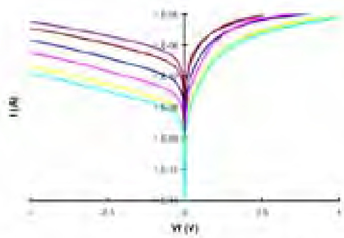
Non-NASA Applications

- Monitoring of military weapons and aircrafts

HIGH-COUNTING RATE PHOTON DETECTORS FOR SPACE OPTICAL COMMUNICATIONS

aPeak, Inc.

2006 Phase I
01-06-9886



Infrared converter IV

Phase I detector module

Technical Objectives

- Modification of the high-gain detector fabrication flow for the integration of the infrared converter deposition process
- Process development, verification, and performance qualification
- Development, qualification, and identification of pathways for improving the bandwidth of high-gain detector arrays

Work Plan

- Task 1: Kickoff/update meeting
- Task 2: Process modification to improve in performance in infrared
- Task 3: Infrared converter-high-gain detector process integration
- Task 4: Test-structure fabrication
- Task 5: Timing performance improvement

NASA Applications

Free-space communications, intersatellite links, space docking, landing, mapping, and high-resolution altimetry, Laser Detection and Ranging (LADAR) and Light Detection and Ranging (LIDAR).

Non-NASA Applications

Low-light level two-dimensional (2D) and three-dimensional (3D) imaging cameras for defense and security applications, airport security, collision avoidance, robotic systems, and autonomous vehicles, as well as generic applications requiring active laser illumination at eye-safe wavelengths.

Identification and Significance of Innovation

We proposed to demonstrate a novel, photon-counting detector, with integrated infrared converter, gain >106, >50% detection efficiency from 1064 to 1550 nm, more than 500 MHz target bandwidth, and more than 100 MHz background counting rate capability by using high gain silicon detector arrays in conjunction with infrared converters. This innovation provides a simple solution to high-bandwidth ground-space and space-space optical communications by mitigating conflicting optical aperture-noise requirements, while providing photon-counting sensitivity at infrared wavelengths. This novel photon counting detector architecture promises to meet all the technical requirements of the detectors for the long-range optical telecommunications program and has the potential to exceed the target bandwidth.

Technology readiness level (TRL) at the end of Phase I

- 2 to 3

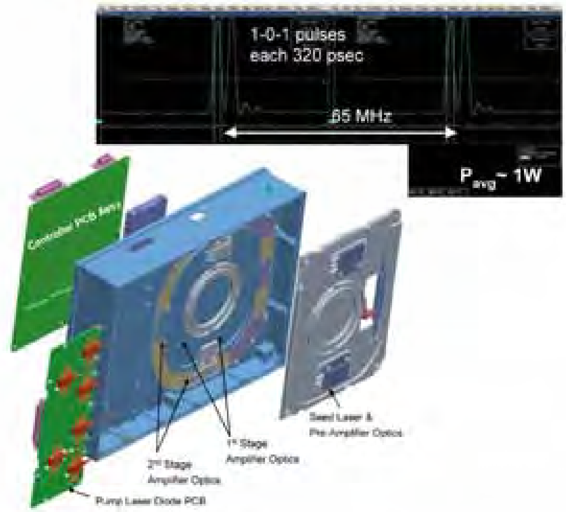
Expected TRL at the end of contract

- 4

SPACE-QUALIFIABLE 1064-nm FIBER-BASED TRANSMITTER FOR LONG-RANGE OPTICAL COMMUNICATIONS

Fibertek, Inc.

2006 Phase I
06-9244



Identification and Significance of Innovation

An all-fiber polarization-maintaining transmitter operating at 1064-nm wavelength is proposed, suited for deep space optical communication. The compact, rugged and efficient design is based on a master-oscillator-power-amplifier (MOPA) architecture. The oscillator is a fiber-coupled single-frequency laser diode, from which an arbitrary pattern of pulse-trains as short as 150 psec can be carved out, based on a proprietary design using state-of-the-art high-speed FPGAs for the electronic modulation. A multistage power amplifier using Yb-doped fibers is used for power-scaling while mitigating all nonlinear optical impairments. The design is compatible with M-ary pulse-position-modulation (PPM) scheme (M = 2, 4, …,256), with time-slot down to 150 ps, that is required for high-bandwidth high-sensitivity deep-space optical communications. Space qualifiable packaging and overall system reliability model are also addressed.

Technical Objectives

- Demonstrate arbitrary pattern optical pulse generation, with pulse width from 0.15 to 10 nsec, and at up to 60 MHz rate.
- Address optical nonlinearity impairments and demonstrate amplification of optical pulse train to ~10 W average powers.
- Develop an overall packaging design and system reliability model, targeting an eventual space qualification.

Work Plan

- Design of an FPGA-based architecture for laser controller
- PCB design, development, and testing for above architecture
- Demonstrate optical amplification to Po~1W and assess nonlinear optical impairments for further power scaling
- Assess packaging for a radiation-hardened design
- Develop a system reliability model with redundancy

NASA Applications

- High-bandwidth deep space optical communications for planetary mission
- High-bandwidth intersatellite communication

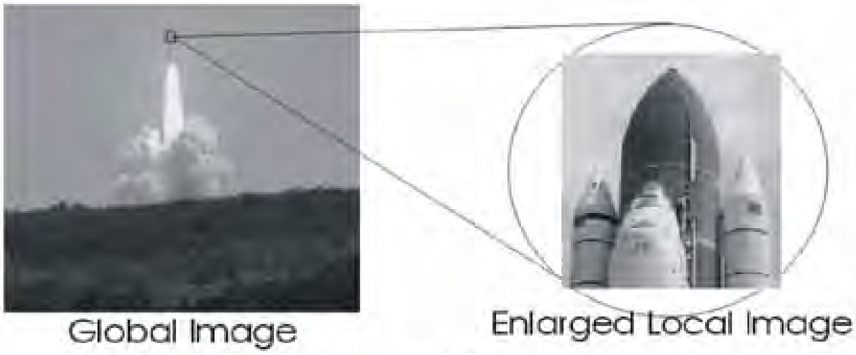
Non-NASA Applications

- Free-space optical communication links
- Applying above approach to high-speed modulated imaging and communication for underwater application

HYPERSPECTRAL FOVEATED IMAGING SENSOR FOR OBJECTS IDENTIFICATION AND TRACKING

New Span Optot-Technology Inc.

2006 Phase I
02.01-8509



Schematic of foveated imaging concept.

Technical Objectives

Develop and demonstrate an innovative optical hyperspectral imaging sensor for identification and tracking of NASA's launch and landing objects. The sensor is expected to possess wide field-of-view with high-resolution measurement of spectral, spatial, and temporal signatures.

Work Plan

- Explore overall technical scheme; construct panoramic imaging optics.
- Build computed hyperspectral imaging system.
- Construct local image magnification channel.
- Develop algorithm for simplified hyperspectral image reconstruction.
- Construct benchtop experimental setup to demonstrate feasibility.

NASA Applications

- Launch object tracking and identification
- Robotic perception and mapping for unmanned space operations
- Tacking and identification of space debris or other manmade objects
- Detecting and tracking of on-Earth objects movement from space vehicles or balloons

Non-NASA Applications

- Missile defense, weapon and sensor platform guidance
- Wide area surveillance
- Aero-vehicle rendezvous, docking, navigation, and guidance
- Quality control, mechanical parts inspection, and nondestructive evaluation

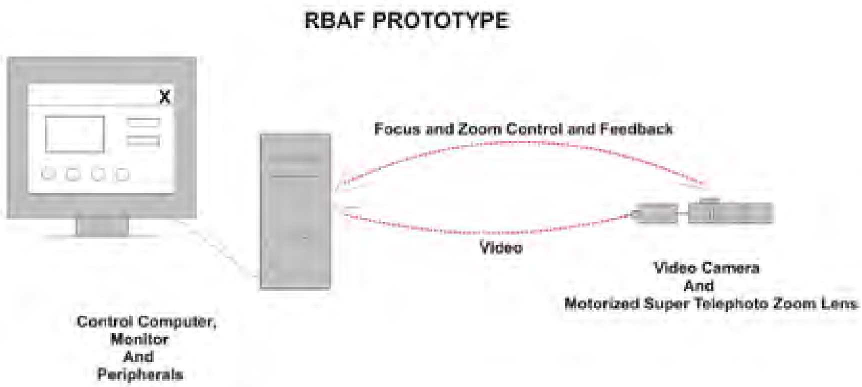
Identification and Significance of Innovation

- Optical identification and tracking sensors have numerous NASA and non-NASA applications.
- These applications require sensors that have wide field-of-view, high spatial resolution, high spectral discrimination ability, and fast response.
- Existing sensors cannot satisfy all of the above requirements.
- Proposed hyperspectral foveated imaging sensor simultaneously possesses properties of wide field of view for global situation awareness, hyperspectral ability for spectral signature identification, high local spatial resolution for object details revealing, and potentially multiplying objects' tracking ability.
- Using fully "solid-state" optical and electronic devices enables fast response, lightweight and low power consumption.
- All involved components are commercially available or easy to fabricate resulting in a cost-effective system.

RANGE-BASED AUTO-FOCUS (RBAF)

Maracel Systems & Software Technologies, LLC

2006 Phase I
02.01-9758



Identification and Significance of Innovation

Range-Based Auto-Focus (RBAF) is a real-time capability that combines both range-based and pixel-based focus techniques and will represent a significant increase in the focus performance of exisiting and newly developed long-range optical systems.

The significance of the RBAF system development is twofold: consistently accurate real-time data products will become available to end users, and more usable data can be reliably collected.

Technical Objectives

- Determine an optimal statistical measure of image quality that is ideal for moving targets.
- Design and validate an algorithm that combines external range with image quality to control focus.
- Refine the algorithms to achieve ideal focus.
- Implement an architectural framework that facilitates field calibration, various video input types, and integration with different types of focus controllers; take advantage of existing systems' capabilities; and focus only on the subject of the imagery.

Work Plan

- Task 1: Capture and display live images.
- Task 2: Implement computer-based focus algorithm.
- Task 3: Develop range-based focus algorithm.
- Task 4: Determine image quality.
- Task 5: Develop imagery-aided focus algorithm.
- Task 6: Use Region-of-Interest for auto-focus zones.
- Task 7: Develop feature tracking capability.
- Task 8: Develop automated calibration techniques.

NASA Applications

- Long-range optics
- Video documentation systems
- Optical tracking systems

Non-NASA Applications

- U.S. and foreign test ranges
- Tactical systems
- Surveillance and security

SPECTRAL IMAGING VISUALIZATION AND TRACKING (SPIVAT) SYSTEM

Physical Optics Corporation

2007 Phase I
02.01-9551

Technical Objectives

The overall goal of this project is to demonstrate for the first time the feasibility of SPIVAT in Phase I. Specific technical objectives include

- Development of a preliminary design of the proposed SPIVAT system
- Identification of technologies for implementing the SPIVAT subsystems
- Integration, testing, and evaluation of the SPIVAT system for enhanced visualization and tracking
- Preliminary establishment of the SPIVAT technology for commercial applications

Work Plan

- Develop detailed technical requirements for proposed SPIVAT system
- Design SPIVAT Phase I system.
- Analyze COTS components to ensure the system requirements are fulfilled.
- Procure and test COTS components.
- Develop hyperspectral/multispectral image fusion algorithms for target visualization and tracking.
- Perform feasibility analysis.
- Explore the commercial potential and product viability.

NASA and Non-NASA Applications

- The success of the SPIVAT project will ensure technology is available to NASA to visualize and track vehicles during launch and landing, with greatly extended capability. The SPIVAT technology can be directly applied to air traffic control, law enforcement, security, search and rescue, fire fighting, hunting, and the automotive industry.

Identification and Significance of Innovation

NASA is seeking technologies to enable a safer and more reliable space transportation capability; specifically, innovative ways are needed to visualize and track vehicles during launch and landing. Current optical imaging systems usually use standard cameras, which are light sensitive, only to visible light, with sufficient contrast only in daytime operation under good weather conditions. POC's proposed SPIVAT system offers a superior and reliable visualization and tracking capability for day and night operation under all weather conditions.

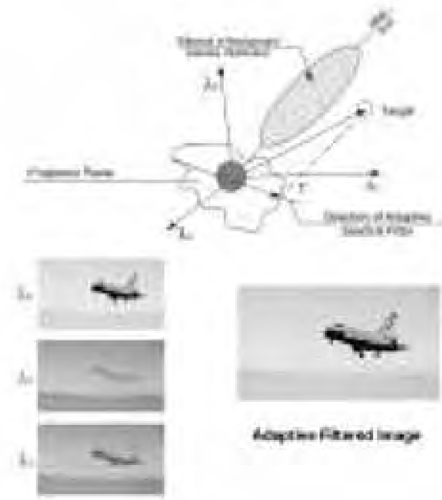
Expected technology readiness level (TRL) range at the end of contract (1–9)

- Phase I: 4
- Phase II: 6

HYPERSPECTRAL IMAGER-TRACKER

Light Prescriptions Innovators, LLC

2007 Phase I
02.01-9731



Hyperspectral Imager-Tracker

Identification and Significance of Innovation

The challenges of launching and landing space vehicles put extreme requirements on NASA operational centers. Use of optical tracking technique allow precise control and in-flight inspection. However, the environment of the two landing areas make visibility difficult. Light Prescriptions Innovators (LPI) proposes to improve the target imaging using a hyperscope with high light-gathering power and high magnification. Adaptive spectral filtering algorithm will produce a high contrast image.

Expected technology readiness level (TRL) at the end of Phase 1

- 4

Technical Objectives

- Develop design of the imager.
- Develop optomechanical design of imager prototype.
- Develop algorithms and software for spectrally adaptive filtering.
- Demonstrate feasibility of the proposed concept by fabricating proof-of-concept prototype and evaluating its performance in laboratory conditions.
- Evaluate potentially commercial applications.

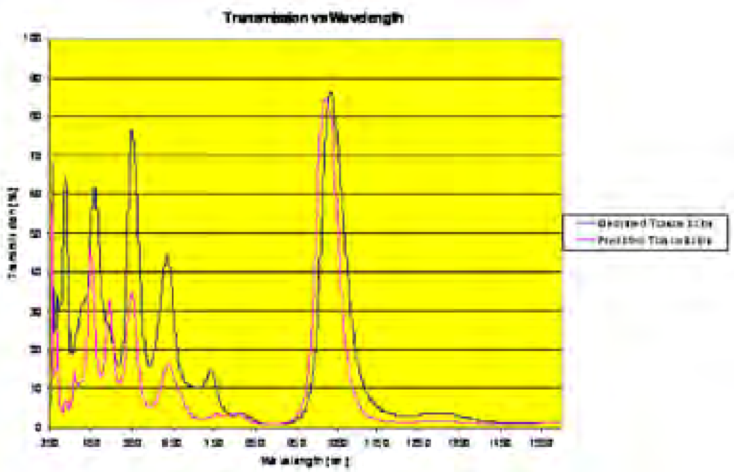
NASA Applications

NASA applications will include optical space objects detection and tracking, space biology by implementation of this technology in microscopy, remote Earth observation for environmental, and resource monitoring.

Non-NASA Applications

Commercial applications will include the development of cameras for environmental monitoring (hazard gases and waste detection), cameras for forensic analysis, and cameras for search and rescue teams. The important application area of hyperscope technology is detection and tracking of camouflage objects for Department of Defense (DOD) programs. It can include compact unmanned vehicles cameras and hand-held cameras for Marine Corps and army.

VERY LARGE SOLAR REJECTION FILTER FOR LASER COMMUNICATION



Induced Transmission Filter For Laser band pass

Surface Optics Corporation

2007 Phase I
01.08-8373

Technical Objectives

- Generate optical constants for thin metal films.
- Generate and evaluate coating designs.
- Build and test coating designs.
- Optimize adhesion of coatings to polymer substrate.
- Fabricate subscale filters on polymer substrate.
- Environmental testing of subscale filters.

NASA and Non-NASA Applications

- Long-range laser communications; interplanetary missions
- Solar cover for laser communication receiver on defense satellite

Identification and Significance of Innovation

Surface Optics Corporation will develop a band-pass filter comprises a visible dielectric mirror and an induced transmission filter applied to two sides of a cast polyimide membrane. The mirror/filter combination will block 95% of the incident solar radiation, while allowing a narrow pass-band for YAG-laser communication.

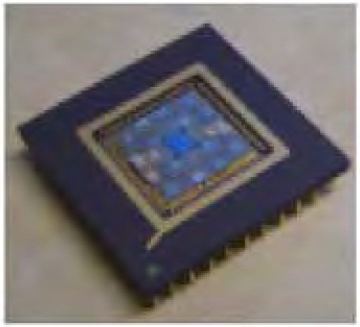
Expected technology readiness level (TRL) at the end of Phase I Contract (1–9)

- 6

HIGH-BANDWIDTH PHOTON-COUNTING DETECTORS WITH ENHANCED NEAR-INFRARED RESPONSE

aPeak, Inc.

2008 Phase I
01.06-9563



Example of the innovation embodiment of the detector array with integrated electronics. The center package contains the photon-counting array mounted in flip-chip, and the perimeter contains the electronics.

Identification and Significance of Innovation

Newest designs in long-range optical communication systems require high-gain, photon-counting arrays operated with high detection efficiency, outstanding temporal resolution, and capability to handle high photon detection rates.

We propose to develop a novel large area, silicon photon-counting detector array in near infrared, operated with moderate cooling, high-detection efficiency, high saturation counting rate, and capable of 20 ps timing resolution. Detector and readout circuit design will be improved to meet the detection efficiency, noise, timing resolution, and linearity requirements of the application.

Expected technology readiness level (TRL) range at the end of contract

- 5

Technical Objectives

- Development of the tuned cavity and mirror fabrication.
- Development of photon counting arrays and fast electronics for increased data rate and improved timing resolution.

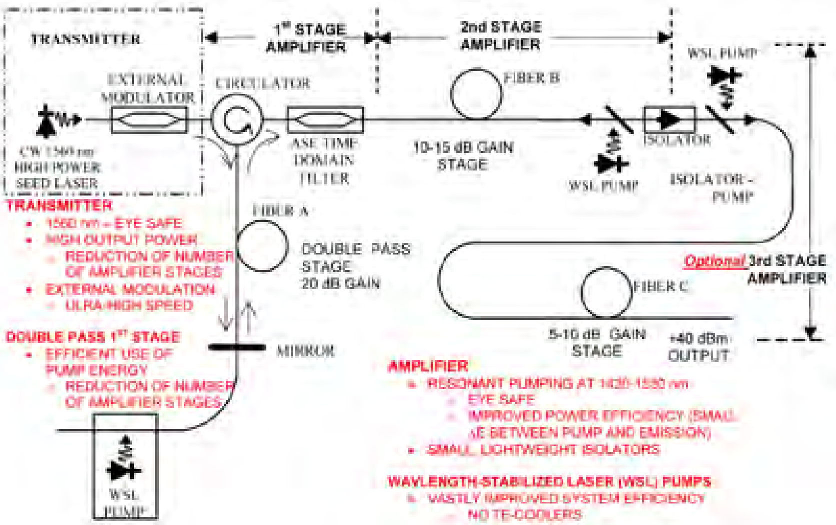
Work Plan

- Detector structure modeling
- Detector process development
- Detector array prototyping
- Electronics development

NASA and Non-NASA Applications

The novel photon-counting array will find application in free space optical communications, space-ground optical links, detection or imaging in media with high turbidity, interferometry, mapping, robotic vision, very high resolution three-dimensional (3D) imaging, hyperspectral imaging, and space docking. In addition to long-range optical communications, larger arrays could be fabricated for single-photon imaging in the infrared and visible with applications to security cameras, imaging of noncooperative targets, single-molecule detection, integration into microfluidic devices, biochips for biomedical applications, fluorescence correlation spectroscopy, etc.

HIGH-EFFICIENCY, HIGH-POWER LASER TRANSMITTER FOR DEEP SPACE COMMUNICATION



Vega Wave Systems, Inc.

2008 Phase I
01.06-9602

Technical Objectives

- Design, fabricate, and characterize a wavelength-stabilized pump source for resonant pumping in the 1430 to 1530 nm Er+-doped absorption band.
- Model the Er+-doped Master Oscillator Power Amplifier (MOPA) to determine fiber lengths, pump coupling methods, and power requirements to achieve 1 kW peak pulse power.

Work Plan

- Wavelength-stabilized pump lasers
  - – Design, fabricate, and characterize pump source for resonant pumping in the 1430 to 1530 nm range using proprietary technology.
- Model the Er+-doped MOPA to determine fiber lengths, pump coupling methods, and power requirements to achieve 1 kW peak pulse power.

NASA Applications

- High-speed, high-power pulse position modulation optical communications links for deep space applications

Non-NASA Applications

- Eye safe pulsed fiber-laser-based sources for material processing and other scientific applications
- High-power wavelength-stabilized pump sources at long wavelength

Identification and Significance of Innovation

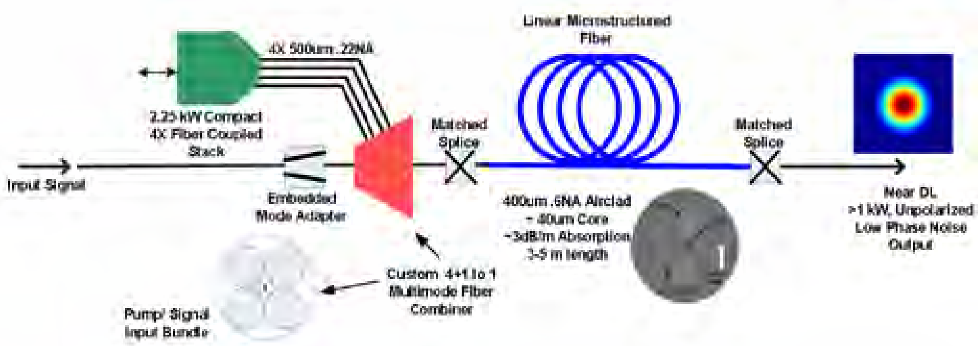
We propose improvements to fiber MOPA transmitters for deep space communications links using several new techniques:

- Operating wavelength of 1560 nm reduces the size and weight of the optical components
- Resonant pumping in the 1430 to 1530 nm band improves pump absorption and hence, wall plug efficiency
- Wavelength-stabilized laser (WSL) pump sources: eliminates power-hungry thermoelectric (TE) coolers, producing a significant improvement in wall plug efficiency
- High-power seed laser with double-pass first-stage amplifier: reduces number of amplifier stages and improves efficiency

HIGH-POWER UPLINK AMPLIFER FOR DEEP SPACE COMMUNICATIONS

Optical Engines, Inc.

2009 Phase I
01.06-8122



Identification and Significance of Innovation

We propose to demonstrate a compact 1-kW fiber amplifier suited for uplink applications:

- Use of multifiber coupled 2.5-Kw laser diode stack greatly reduces size and cost
- Etched taper bundle combiner creates an all fiber architecture for reliable operation
- PCF Fiber amplifiers improve the efficiency of the system, and allows for a higher level of pump integration also reducing potential non linearities

Expected technology readiness level (TRL) at the end of the contract

- 4

Technical Objectives

Use the multifiber coupled 2.5-kW laser diode stack and etched taper bundle all fiber 4+1 to 1 combiner with photonic crystal fiber (PCF) to assemble, demonstrate, and characterize and Yb-based 1064-nm 1-kW power amplifier.

Work Plan

- Construct 2.5-kW fiber coupled stack into 4500-um fibers.
- Construct 4+1 to 1 etched taper bundle fiber combiner.
- Assemble fiber amplifier with above components and PCF Fiber.
- Demonstrate and characterize 1-kW fiber amplifier.

NASA Applications

- High-power optical communications uplink transmitter and beacon laser
- High power source for remote sensing

Non-NASA Applications

- High power source for directed energy applications
- Fiber laser source for material-processing applications

HIGH-PERFORMANCE NEGATIVE FEEDBACK NEAR INFRARED (NIR) SINGLE PHOTON COUNTING DETECTORS AND ARRAYS

Amplification Technologies, Inc.

2009 Phase I
01.06-8219

Technical Objectives

- Develop the internal discrete amplification design in InGaAs/InP material system to achieve stated goals.
- Develop initial design of the detector array that meets or exceeds the desired performance characteristics.
- Develop fabrication processes for the fabrication of the internal discrete amplifier detectors and arrays.
- Fabricate, test, and analyze the results of the fabricated devices in Phase II.
- Deliver fully functional InGaAs/InP-based photodetectors and arrays with internal discrete amplification to NASA at the conclusion of Phase II.

NASA Applications

- Long-range space to ground communication links
- Intersatellite links
- Earth orbiting to ground optical communication
- Quantum cryptography
- Three-dimensional (3D) imaging
- Night vision

NASA and Non-NASA Applications

- Optical communication
- Light Detection and Ranging/Laser Detection and Ranging (LIDAR/LADAR) remote sensing

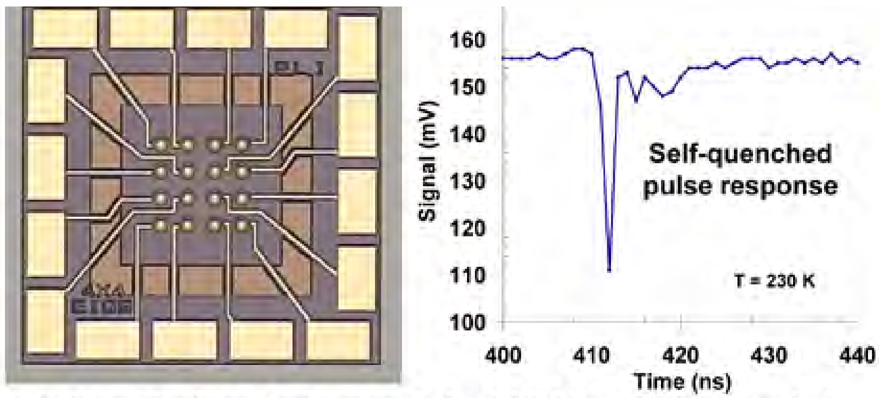
Identification and Significance of Innovation

New photon-counting photodetectors and arrays are proposed to advance the state of the art in long-range space optical communications. The proposed detector operates at 1000 to 1600 nm wavelengths and have high detection efficiency, low jitter, high bandwidth, very high internal gain, and extremely low excess noise. The detector design will be based on the invented breakthrough technology of discrete amplification. The new detector will enable meeting the goals of long-range space optical communication applications.

NEGATIVE FEEDBACK AVALANCHE DIODE (NFAD) ARRAYS FOR SINGLE-PHOTON OPTICAL COMMUNICATIONS AT 1.5 mm

Princeton Lightwave, Inc.

2009 Phase I
01.06-9687



Photograph of proof-of-concept 4 x 4 NFAD array to be scaled

Identification and Significance of Innovation

We propose to develop large pixel-count (e.g., 80 x 80) single photon counting detector arrays suitable for deployment in spacecraft terminal receivers supporting long-range laser communications. We will leverage initial success in monolithically integrating "negative feedback" elements with state-of-the-art single photon avalanche diodes to realize large-scale (NFAD) arrays in which array pixels have high counting rate, high detection efficiency, low dark count rate, low after pulsing, and low timing jitter. These devices rapidly self-quench, which reduces afterpulsing and supports higher photon counting rates. Since NFADs self-quench and self-arm, they can be deployed with greatly simplified back-end circuitry. NFAD arrays have significant promise for enabling space-qualifiable focal plane arrays that serve applications requiring 1.5 µm single photon detection.

Expected technology readiness levels (TRLs) at start and end of contract

- 2
- 4

Technical Objectives

- Design NFAD to reduce afterpulsing by 3X.
- Design NFAD to achieve timing jitter <70 ps.
- Establish reproducibility and uniformity of negative feedback on scale of large arrays.

Work Plan

- 1.A. Characterize afterpulsing of existing PLI discrete NFADs.
- 1.B. Develop afterpulsing models to describe Task 1.A. results.
- 1.C. Define optimal NFAD design for 3X reduction in afterpulsing.
- 2.A. Characterize timing jitter of existing PLI discrete NFADs.
- 2 B. Develop timing jitter models to describe Task 2.A. results.
- 2 C. Define optimal NFAD design to achieve < 70 ps timing jitter.
- 3.A. Fabricate negative feedback thin-film test structures.
- 3.B. Characterize feedback test structures for uniformity and scalability.
- 4. Definition of optimal NFAD pixel design and array structure.

NASA Applications

- Free-space optical communications, including space-based laser communications links
- Active remote sensing optical instruments Light Detection and Ranging (LIDAR)

Non-NASA Applications

- Range-finding and Laser Detection and Ranging (LADAR) applications
- Commercial LIDAR systems
- Free space optical (satellite) communications
- Single photon counting for fluorescence, photoluminescence, and photo emission applications

HOLE-INITIATED-AVALANCHE, LINEAR-MODE, SINGLE-PHOTON-SENSITIVE AVALANCHE PHOTODETECTOR WITH REDUCED EXCESS NOISE AND LOW DARK COUNT RATE

A proven rad-hard multi-gain-stage APD technology has high gain (> 1200) with low excess noise ($k < 0.02$). In this program, the device will be fabricated without aluminum-containing alloys, which is anticipated to reduce dark count rates by a factor of 200.

Voxtel, Inc.

2010 Phase I
01.04-9119

Technical Objectives

- Fabricate single elements of varying diameter
  – Allows verification of changes in gain and dark current vs. diameter
- Test and characterize device gain, dark current, capacitance, and count rate
  – Verify gain (>1200), excess noise (k <0.02), breakdown uniformity (<2 V Phase I and <1 V Phase II)
- Fabricate segmented arrays
- Design segmented detector readout integrated circuit (ROIC), including low-noise (<40 e– RMS) segmented pixel uniformity correction, in-pixel thresholding, etc.
- Phase II: Fabricate working single-photon-sensitive receiver, test for gamma and proton radiation tolerance, lifetime test, and deliver working receiver in hermetic housing

NASA Applications

- Deep space optical communications
- Light Detection and Ranging (LIDAR) receiver for atmospheric profiling
- Rangefinder for profiling
- Star trackers
- Three-dimensional (3D) imaging Light Detection and Ranging/Laser Detection and Ranging (LIDAR/LADAR), when configured into arrays
- Astronomical imaging over UV-SWIR range (with substrate removed)

Non-NASA Applications

- Automotive navigation (adaptive cruise control)
- Telecommunications
- Quantum cryptography
- Military missile seekers and unmanned aerial vehicles/unmanned ground vehicle (UAV/UGV) navigation

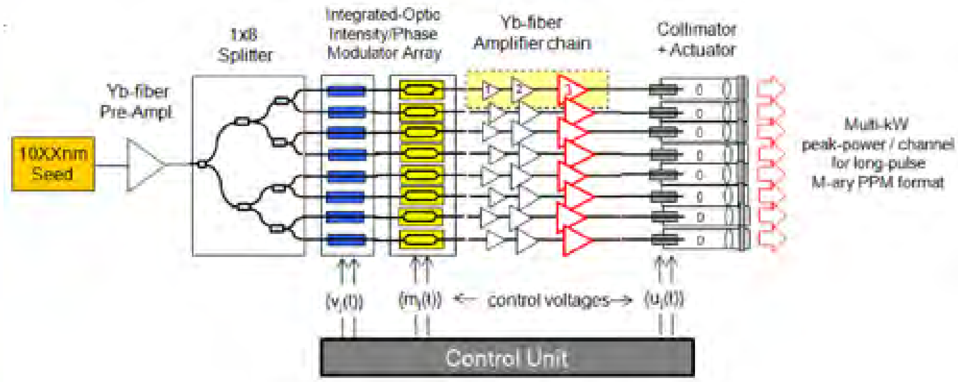
Identification and Significance of Innovation

- Multi-gain-stage APD process proven to exhibit high gain (M > 1000) with low excess noise (k = 0.02).
- Reliable back-illuminated mesa InGaAs/InP APD process.
- Proven tolerant to proton irradiation >10 krad.
- Eliminating aluminum alloys will reduce dark current by 2 orders of magnitude.
- Hole-initiated avalanche is anticipated to increase temporal response by 5 to 10 times, allowing GHz count rates in single-element devices.
- Technology readiness levels (TRLs) 3 and 4 at commencement. Electron avalanche device has been built, though the hole-initiated multistage device has not. Similarly, radiation testing has been performed on the electron-avalanche device.

MULTI-kW UPLINK FIBER-LASER BEACON WITH AGILE SIGNAL FORMAT

Fibertek, Inc.

2010 Phase I
01.04-9435



Architecture of Uplink Laser Beacon Architecture

Identification and Significance of Innovation

Uplink laser beacons for deep space communications, benefit greatly from migrating to 1010 to 1030 nm wavelengths, via use of silicon APD receivers on the spacecraft. Fibertek has developed an uplink laser transmitter testbed using a multistage fiber MOPA platform, that is scalable to a multiaperture architecture. Preliminary demonstration for 1064 nm operation has shown multi-kW peak powers using long-pulse slot (>100 nsec) based M-ary PPM format. The highly flexible platform developed at Fibertek, also corrects for pulse-distortion, and pulse-train variations, inherent in such multi-kW long-pulse variable-symbol PPM data format. This SBIR proposal aims to develop and demonstrate the feasibility of a clear technical roadmap to translate this to shorter wavelengths <1030 nm, as well as to further optimize the uplink laser beacon transmitter for M-ary PPM data formats, using FPGA-based adaptive control.

Expected technology readiness level (TRL) at end of SBIR Ph II

- 6

Technical Objectives

- Demonstrate CW and pulsed (M-ary pulse position modulation (PPM)) fiber Master Oscillator Power Amplifier (MOPA) for efficient operation in the 1010 to 1030 nm wavelength region.
- Develop an overall system design for uplink laser beacon on the roadmap for deep space missions.

Work Plan

- Build and test verification of multistage fiber MOPA producing P_{avg}>30 W, optimized for 1010 to 1030 nm wavelength region.
- Develop an iterative/adaptive algorithm control of M-ary PPM symbol format, with needed optical pulse control.

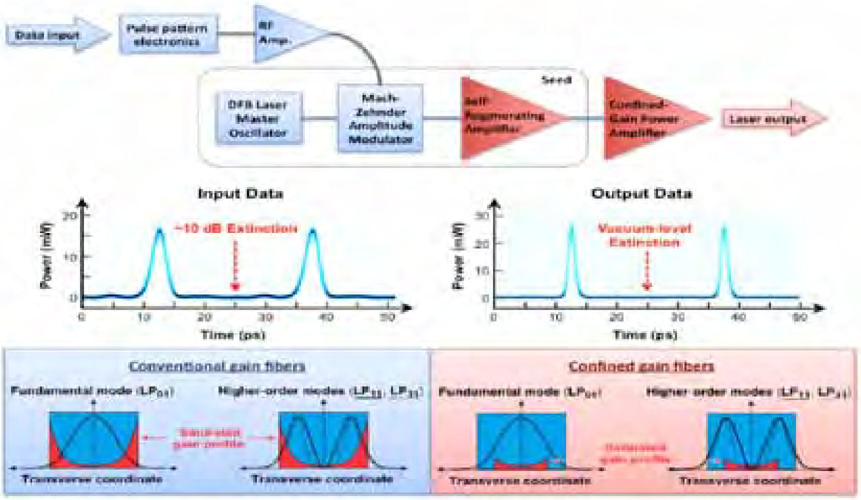
NASA Applications

- Uplink laser beacon for deep space communication and telemetry.
- Subscale version as uplink beacon for lunar communications and ground-station to low-Earth-orbit/geostationary-Earth-Orbit (LEO/GEO) satellite communication.

Non-NASA Applications

- Ground station to military satellite communication/telemetry
- Ground to space (near-Earth) power projection for small payload propulsion
- Power projection for directed energy application and testing

HIGH-EFFICIENCY DATA-RATE-SCALABLE LASER TRANSMITTER FOR INTERPLANETARY OPTICAL COMMUNICATION



RAM Photonics

2011 Phase I
01.04-8043

Technical Objectives

- Modulator qualification
- Digitizing parametric amplifier extinction assessment
- Digitizing parametric amplifier gain limits
- Pulse sharpening qualification
- SBS limitations on fiber amplification
- Power amplifier efficiency and in-band noise assessment
- Assessment of propagation penalty
- Laser transmitter system design
- Documentation and reporting

Work Plan

- Task 1: Master oscillator and modulator qualification (1 month)
- Task 2: Parametric amplifier model development (2 months)
- Task 3: Digitizing parametric amplifier optimization (3 months)
- Task 4: Imposed SBS limitations (1 month)
- Task 5: Er-doped fiber amplifier model development (1 month)
- Task 6: Confined-gain fiber power amplifier efficiency optimization (3 months)
- Task 7: Receiver penalty due to beam quality (1 month)
- Task 8: Documentation and reporting

NASA Applications

- Rate-scalable optical communication
- Sensor and imaging links
- High-precision ranging
-

Non-NASA Applications

- Deep-sea sensing
- Optical wireless

Identification and Significance of Innovation

Identification of opportunity:

- High-rate directional communication
- Deep space and intermediate-range data links

Significance of innovation:

- Self-regenerated parametric amplifier
- High-fidelity, high-power pulse generation
- Brillouin-mitigated power amplification
- Propagation penalty mitigation

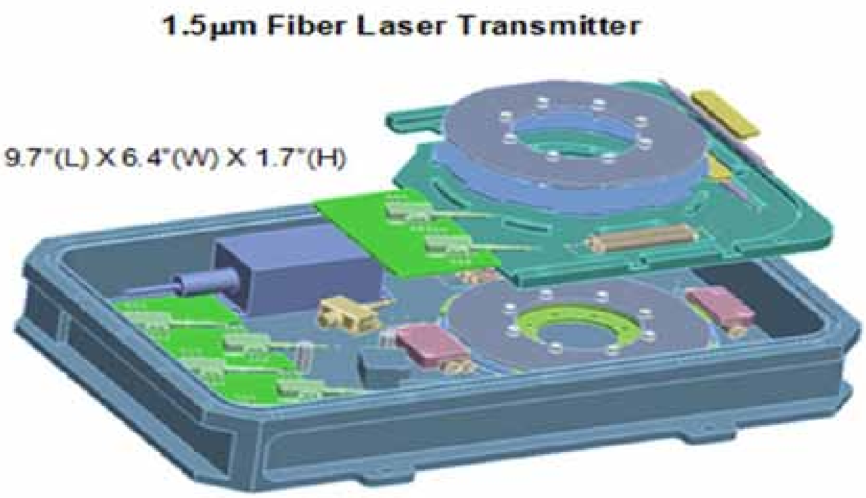
Estimated technology readiness levels (TRLs) at beginning and end of contract

- 1
- 2

DOWNLINK FIBER LASER TRANSMITTER FOR DEEP SPACE COMMUNICATION

Fibertek, Inc.

2011 Phase I
01.04-9718



Identification and Significance of Innovation

NASA's SCaN roadmap, calls for an integrated network approach to communication and navigation needs, from near-Earth to planetary missions. Laser based optical communication links for space provides an order of magnitude higher data rates than corresponding RF links. In addition, due to much smaller size, weight & power burden to spacecraft, resources are available to enhance or extend science missions. Tremendous progress made in 1.5 um & 1-um fiber laser/amplifier technologies, their power scaling, and availability of reliable high-power components, makes such transmitters feasible for space mission. In this SBIR proposal, we propose to develop 1.5 um fiber-amplifier based laser transmitters, with Pav>4W, and compatible with a variety of M-ary PPM formats, that have a clear path to space-qualification roadmap. In addition, power-scaling to 10W, athermal operation over temperature range, and improved power efficiency, are addressed. Limited scope qualification tests are also planned.

Estimated technology readiness levels (TRLs) at beginning and end of contract

- 4
- 6

Technical Objectives

- 1.5 um fiber laser transmitter, with P>4 W (Ppk>0.64 kW) compatible with a range of M-ary pulse position modulation (PPM) formats. Stretch goal of design validation to Pav~10 W, Ppk 1.6 kW.
- A thermal operation over wide temperature range, while maintaining high overall power efficiency (>15%)
- Packaging design (fiber-amplifier assembly only, i.e., excluding electronics) consistent with space-qualification roadmap
- Limited scope qualification testing (in Phase II)

Work Plan

- Design and Lab verification of 1.5 mm fiber Master Oscillator Power Amplifier (MOPA) for all key performance parameters, with techniques for SBS mitigation
- Optimize and validate design by comparing with predicted performance from a comprehensive fiber MOPA simulation model
- Evaluate a thermal operation, via use of wavelength stabilized pumps, and fiber-amplifier thermal management
- Packaging concept and qualification plan for a space qualification roadmap

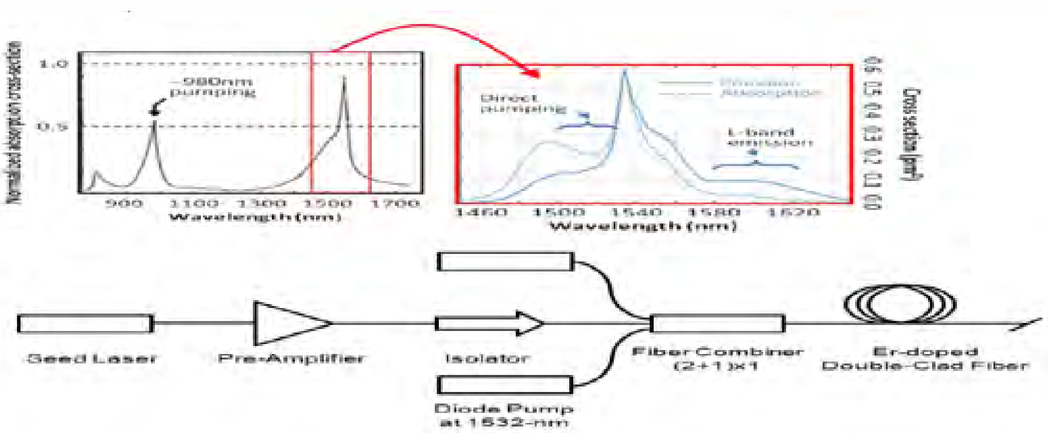
NASA Applications

- High-bandwidth lasercom flight terminal for planetary missions, as well as for various lunar and Mars relay links, per Space Communications and Navigation (SCaN) roadmap.
- Space-qualifiable, robust, compact, and efficient Light Detection and Ranging (LIDAR) component, e.g., CO_2 sensing, pumping optical parametric oscillator/optical parametric amplifier (OPO/OPA) for a mid-Infrared LIDAR source.
- Coherent LIDAR component technology for aviation-safety sensor, e.g. windshear/turbulence, wake-vortex hazard, etc.

Non-NASA Applications

- High bandwidth low-Earth-orbit/geostationary-Earth-Orbit (LEO/GEO) satellite communication for the military
- High bandwidth real-time feed from multiple unmanned aerial vehicles (UAVs), via LEO/GEO crosslinks
- High bandwidth GEO crosslinks for commercial satcom
- In-flight wind sensor, to aid precision dropping of supplies in war zone.

HIGH-EFFICIENCY RESONANTLY PUMPED 1550-nm FIBER-BASED LASER TRANSMITTER



nLight Photonics

2012 Phase I
H9.01-8264

Technical Objectives

Under the proposed Phase I program, nLight will design and demonstrate high-efficiency 1532-nm single emitter diode lasers that meet the specified power and efficiency objective. nLight will design, fabricate, test, and deliver to NASA (or a recipient of their choosing) two 15-W (rated) conductively cooled diode laser pump modules, coupled to a 105-um core, 0.22-NA fiber, with >32% wall-plug efficiency. The modules are based on nLight's Pearl platform. This effort will represent the confluence of multiple technologies in which nLight has deep experience, making nLight well-positioned to meet the specifications set forth in the solicitation. If successful, nLight will propose a Phase II continuation of the program to further improve the power and efficiency of the 1532-nm pump module to >20 W and 40%, respectively. During the Phase I program, nLight will perform modeling and assessment on eye-safe fiber amplifier architectures suitable as a laser transmitter for space communication, and develop in Phase II a high-efficiency 1550-nm-fiber laser transmitter based on resonantly pumped Er-doped fiber amplifier system, demonstrating >23 W average power and >23% wall-plug efficiency.

NASA Applications

A potential NASA application of the proposed fiber-based master oscillator power amplifiers at 1550 nm is laser transmitters that meet the efficiency, power and modulation requirement of deep space optical communication. In addition, such system can provide precision range and velocity tracking for spacecraft navigation, and can also be used in direct energy detection Light Detection and Ranging (LIDAR) systems for atmospheric research and meteorology.

Non-NASA Applications

Commercial applications may be in materials processing where the eye-safe wavelength and high peak power capability of the fibers developed may provide an advantage in terms of application speed or quality. It is expected that these high average power, high pulse energy eye-safe fiber lasers will be useful in materials processing, biomedical, and other light industrial applications.

Identification and Significance of Innovation

There is a considerable interest in developing fiber-based laser transmitters at the 1.5 um wavelength for free-space optical communications. At this wavelength range, the atmosphere is largely transparent. Also, reliable commercial off-the-shelf components for optical pulse generation and control, as well as mature, high-performance detectors are readily available. To meet the high wall-plug efficiency requirement of laser transmitters in space communication, nLight proposes high-efficiency, high-average power 1550-nm laser transmitter system that is based on Er-doped fiber amplifier resonantly pumped by high efficiency 1532-nm fiber-coupled diode laser pumps. The overall efficiency is improved by (1) optimizing diode laser and fiber coupling for maximum efficiency of 1532-nm pumps, (2) developing resonant pumping of the fiber amplifier for minimum quantum defect, and (3) design and development of Er-doped fiber amplifier capable of achieving high optical-to-optical efficiency.

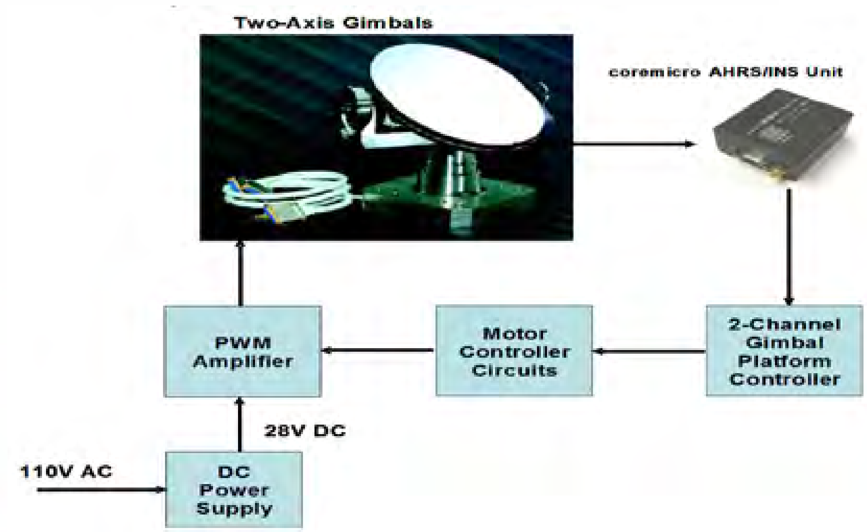
Estimated Technology readiness levels (TRLs) at beginning and end of contract

- 3
- 4

A MINIATURE POINTING AND TRACKING ISOLATION PLATFORM

American GNC Corporation

2012 Phase I
H9.01-8425



Identification and Significance of Innovation

Inertial stabilization and relative attitude control are the two key elements constituting the proposed accurate pointing control. Inertial stabilization allows isolation from interference and vibration. Relative attitude control is used for target tracking and to compensate pointing drift caused by gyro drift and the Earth's rotation. The pointing and tracking platform is an inertially controlled/stabilized compact, light weight, low power, broad bandwidth disturbance rejection and/or isolation platform. The operation of the laser designator requires stable and accurate line-of-sight alignment and stabilization for the beam line. The accurate pointing and attitude/orientation control is realized by two parts: inertial stabilization/control and relative attitude/orientation control. The former is the basis for the accurate attitude/orientation control that isolates the interference and vibration of the vehicle.

Estimated technology readiness levels (TRLs) at beginning and end of contract

- 3
- 4

Technical Objectives

The objective of this project is to demonstrate the feasibility of a miniature, microelectromechanical systems (MEMS) intertial measurement unit (IMU) based, accurate alignment and stabilization system for beam pointing of a laser designator. In Phase I of this project, first, using the simulation tools and experimental systems of American GNC Corporation, modeling and implementation evaluation of the proposed MEMS-based inertial pointing system are performed. Through the modeling and simulation of the closed-loop system, the implementation method and the specification of the MEMS devices and pointing system will be further investigated. Then, an inertial motion measurement device test and tuning are performed. MEMS gyros for pointing stabilization are integrated into the platform structure. Next, system integration of the MEMS stabilization platform is investigated. An accuracy evaluation of the pointing stabilization system is performed. Finally, the mechanical structure of the stabilization platform and the integration of the MEMS with the system's mechanical and electronic components is proposed and investigated.

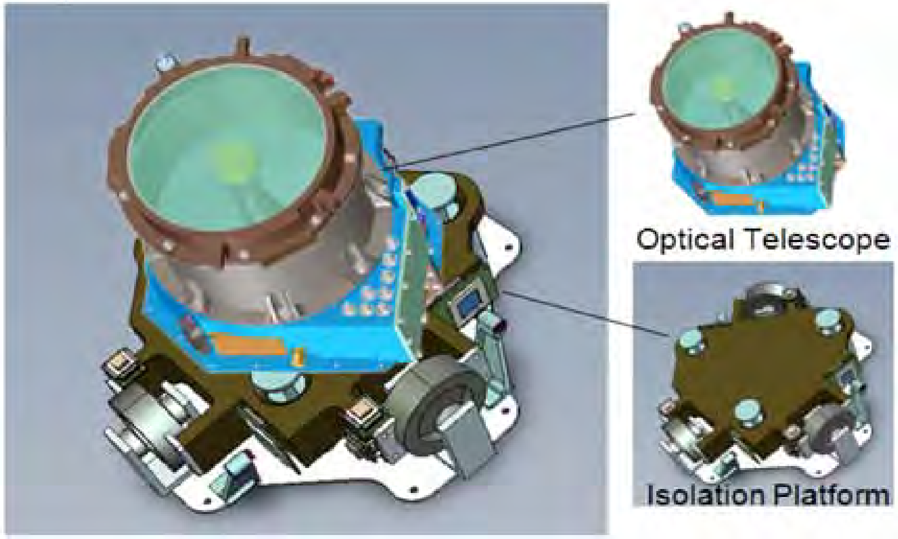
NASA Applications

This stabilization pointing and tracking isolation platform is of small size, light weight, low power, fast steering, and reduces cost in design and production. It finds wide applications in spaceborne vehicles for large telescope stabilization control, optical communications, antenna pointing, telescope stabilization, laser pointing and control, and vehicle guidance.

Non-NASA Applications

Its properties of small size, low cost, light weight and broad bandwidth disturbance rejection allows its utilization in many commercial applications including pointing control, motion, and vibration isolation. Specific examples include target designation, stabilization control, optical pointing, and laser and telescope pointing control.

VIBRATION ISOLATION PLATFORM LONG-RANGE OPTICAL COMMUNICATIONS



Controlled Dynamics, Inc.

2012 Phase I
H9.01-9372

Technical Objectives

Phase I develops the proposed design concept, performs architecture trade studies, and predicts performance to establish the feasibility of the approach. Using an available free-floating isolation platform and a two-axis low-g testbed, the design concept is prototyped and demonstrated on hardware in a simulated low-g environment technology readiness level of 5 (TRL–5).

Phase II proceeds with the development of a prototype system that will be space qualified through comprehensive ground testing (TRL–6). Technology demonstration flight tests will be proposed on sRLVs and/or International Space Station (ISS) platforms (e.g., WORF and OPALS upgrade), achieving a TRL–7 maturity by the end of Phase II.

NASA Applications

- Deep Space Planetary Missions
- Deep Space Optical Terminal (DOT) Project
- Space Communications and Navigation (SCaN) Program
- Laser Communications Relay Demonstration (LCRD) Mission
- Optical Payload for LAsercomm Science (OPALS) upgrade

Non-NASA Applications

By providing component-level isolation and stabilization at the optical payload, this approach does not impose any unusual constraints on the host vehicle. This makes the technology broadly applicable to a wide range of vehicles including sRLVs,orbital RLVs, Earth-orbiting satellites (even the simplest thruster-only designs), and deep space vehicles.

Identification and Significance of Innovation

Optical communication links provide higher data transfer rates with lower mass, power, and volume than conventional radiofrequency links. For deep space applications at long operational ranges, high performance stabilization of the space terminal data link is required. To meet this need, Controlled Dynamics, Inc., proposes a novel application of our free-floating isolation platform. Based upon a shuttle-proven technology, this approach yields 6 degrees of freedom (DOF) isolation from the disturbances of the host vehicle while providing high-bandwidth active stabilization to attenuate both payload disturbances as well as any residual disturbances transferred from the base across the power/data umbilical. The proposed approach is designed to achieve better than 0.5 microradian-rms stabilization for all frequencies above 0.1 Hz when operating in a space environment.

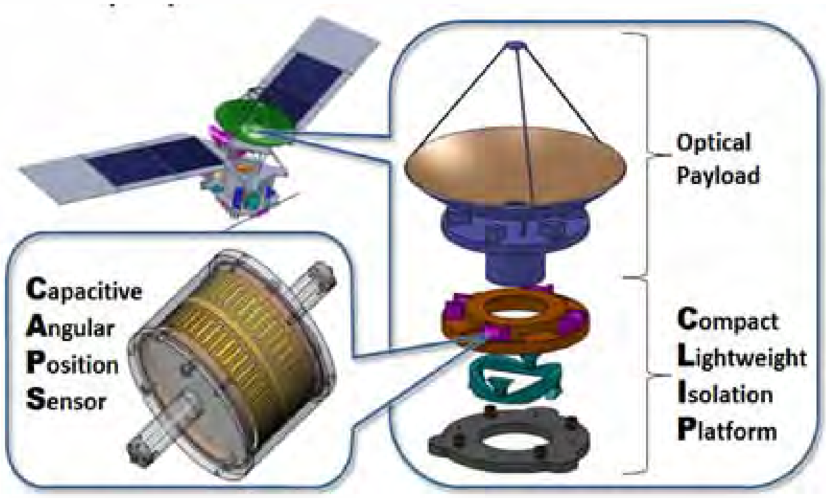
Estimated technology readiness levels (TRLs) at beginning and end of contract

- 3
- 5

COMPACT, LIGHTWEIGHT ISOLATION PLATFORM (CLIP)

Applied Technology Associates

2012 Phase I
H9.01-9621



Identification and Significance of Innovation

NASA has a critical need for improved bi-directional data transmission rates from a variety of spacecraft to Earth. NASA estimates that the current Mars to Earth transfer rate of 6 Mbps might be increased to 600 Mbps using a laser communication system. Beam jitter caused by spacecraft-based motion must be reduced to submicroradian levels to enable beaconless optical beam pointing. ATA will create a CLIP that will host the laser communication (LC) collimator telescope and provide a stabilized platform to prevent the 150-microradian spacecraft disturbance environment from reaching the LC terminal. To enable that stabilization, ATA will develop an ultra-low angular noise CAPS. The proposed sensor will have low power and high reliability, which ATA will demonstrate by producing TRL 4 prototypes in Phase I. ATA will develop the CLIP, a 0.5 microradian residual motion stable platform, in Phase II for programs like iROC.

Estimated technology readiness levels (TRLs) at beginning and end of contract

- 3
- 4

Technical Objectives

- Develop the Capacitive Angular Position Sensor (CAPS).
- Develop design concept for Compact, Lightweight Isolation Platform (CLIP) with CAPS.

The goal is to produce a stable platform at technology readiness level (TRL) 4 to host laser communication payloads by reducing spacecraft jitter to 0.5 micro-rad. Phase II will build (CLIP) engineering development unit (EDU) to support long-range optical communications for space.

Work Plan

- Design and characterize prototype hardware for the CAPS using applied technology associates (ATA's) new innovative capacitive sensing technology. The CAPS will provide base motion measurement similar to world-class gyros, but for smaller size, weight, and power.
- Gather requirements, develop system architecture, and performance models for the CLIP.
- Specify design concept and develop plan for building a CLIP EDU for a Phase II proof-of-concept demonstration.

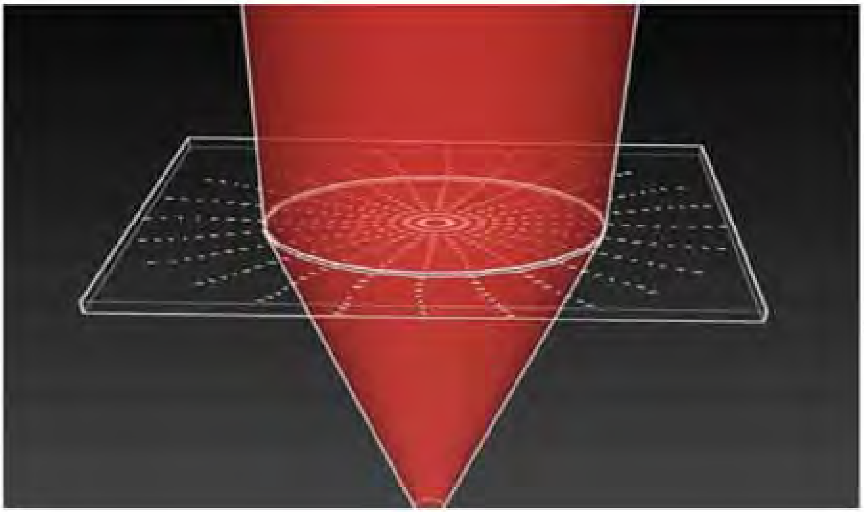
NASA Applications

ATA-developed CLIP concept is the basis for NASA's laser communication terminal for the LLCD and LCRD programs. ATA's proposed CLIP and CAPS may support NASA integrated Radio and Optical Communications (iROC) project's laser collimator.

Non-NASA Applications

Air Force's Space Laser Communication Terminal (SLCT), DARPA's Laser Weapon System Module (LWSM), Lockheed Martin's Space Optical Tracking (SpOT), Navy's Laser Weapon System (LaWS), and Marine's Ground Based Air Defense (GBAD).

LARGE OPTICAL TELESCOPE BASED ON HIGH-EFFICIENCY THIN-FILM PLANAR DIFFRACTIVE OPTICS



BEAM Engineering for Advanced Measurements

2014 Phase I
H9.02-8530

Technical Objectives

- Subscale diffractive optical elements will be designed, fabricated, and tested in Phase I.
- Intermediate objective is to develop methods for precise and accurate writing of grating pattern on large aperture diffractive optical elements.
- Testing will address critical performance parameters related to top-level telescope requirements.
- Optical resolution testing on subscale diffractive elements will validate design concept for achieving <20 micro-rad spot size with full-scale elements.
- Testing of the amplitudes of scattering and parasitic diffraction will validate design concept for achieving operation as close as 5 degrees from the Sun.

NASA Applications

- Major application is to the Ground-Based Telescope Assembly for deep-space optical communications
- Also applicable to other future NASA laser communications programs
- Possible application to the flight laser transceiver of deep space optical communications systems

Non-NASA Applications

- Fabrication methods to be developed on this program are applicable to commercial laser communications transmitters and receivers
- Possible Department of Defense (DoD) applications include laser range finders, laser target markers, and laser designators

Identification and Significance of Innovation

- Apply diffractive optics to the design of the optical telescope, a part of the Ground-Based Telescope Assembly.
- Use of diffractive optics will allow drastic optical telescope cost and weight reductions.
- Cost reduction is due to the elimination of tightly toleranced reflective optics used in conventional telescopes.
- Weight reduction is due to replacement of tightly toleranced, massive reflective optics with loosely toleranced, thin diffractive optics.
- Additional indirect cost reduction of pointing system due to reduced weight of telescope structure.

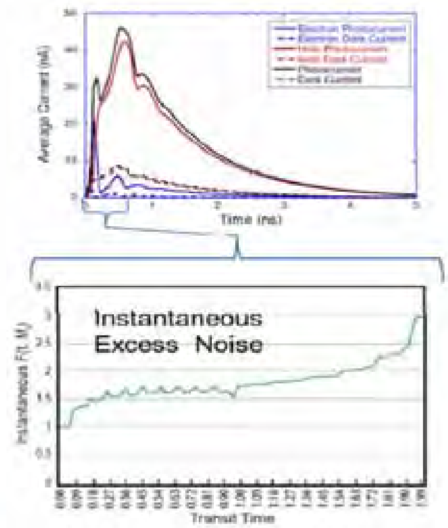
Estimated technology readiness levels (TRLs) at beginning and end of contract

- 5
- 7

HIGH COUNT RATE SINGLE-PHOTON COUNTING DETECTOR ARRAY

Voxtel, Inc.

2014 Phase I
H9.01-8912



A high gain APD is proposed, which has extremely low excess noise during the decision event of the optical receiver. Using time-over-threshold photo-events are discriminated from dark events

Identification and Significance of Innovation

An optical communications receiver requires efficient and high-rate photon-counting capability so that the information from every photon, received at the aperture, is processed. This is particularly true in space platforms, where the information contained in every additional photon detected directly translates into lower system size, weight and power (SWAP). To address this need, a near-infrared (NIR) high-gain, low-excess noise APD array will be developed for photon counting flight receivers.

The proposed APD array technology is capable of a single photon detection efficiency (SPDE) greater than 50% at 100 Mhz count rate. It will be shown possible to discriminate photo-generated events from dark-initiated events, so that when the APD is configured with a low noise readout circuit, with sufficient bandwidth detection circuits, that low false alarm rates (FARs) can be achieved.

Estimated technology readiness levels (TRLs) at beginning and end of contract

- 3
- 4

Technical Objectives

- Using numerical models, optimize avalanche photodiode (APD) epitaxial layers.
- Grow the APD epitaxial material.
- Fabricate APD detector arrays and test their performance.
- Prepare a GHz-rate readout integrated circuit (ROIC) for testing and characterize the SCM APD.

Work Plan

- Using Monte Carlo analysis, the APD design will be optimized. Simulations will show a high probability of photon detection at 10s Mhz count rates.
- Candidate device designs will be epitaxially grown, and a series of single-element and small size arrays will be fabricated and tested. A multi-GHz ROIC, with sampling circuits, will be prepared to test and evaluate the APD.

Tasks

- Perform system engineering.
- Optimize high-gain APD epitaxial structures.
- Optimize APD architecture, fabrication, and processing.
- Prepare VX–805b ROIC for testing and demonstrating APD.

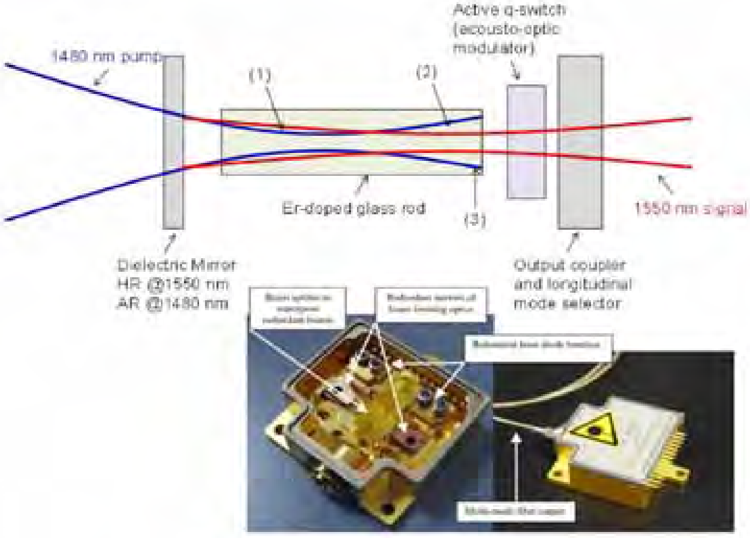
NASA Applications

NASA applications for the innovation include optical communications, Laser Detection and Ranging (LADAR) based autonomous navigation and landing systems, three-dimensional (3D) imaging for docking systems, and laser ranging.

Non-NASA Applications

Military applications include laser range finding, LADAR imaging and autonomous navigation. Commercial applications include automobile driver assistance systems and collision avoidance systems.

HIGH-EFFICIENCY AND POWER LASER TRANSMITTER FOR DEEP SPACE COMMUNICATIONS



Freedom Photonics LLC

2014 Phase I
09.02-8941

Technical Objectives

The overall technical objective for this Phase I effort is to perform critical design studies, simulations, and key experimental evaluation to prove the feasibility of the approach for generating a radiation hard Phase II prototype pulse-position-modulation (PPM) transmitter design with robust packaging, which meets the following performance targets:

- Wavelength: 1550 nm
- Spectral bandwidth: Transform-limited
- Optical-to-optical efficiency: >70%
- Pulse width: 0.2 to 16ns
- Average output power: 20 W
- Total wallplug efficiency: >25%
- Total mass: <5 kg

Work Plan

- Task 1: Epitaxial design and growth of 1480-nm pump laser material
- Task 2: High-efficiency 1480-nm pump laser fabrication and testing
- Task 3: Er-doped glass Q-switched laser design and benchtop demonstration
- Task 4: Phase II PPM transmitter design and layout

The deliverables of the Phase I program will be progress reports and a critical hardware demonstration

NASA Applications

The first planned product for the PPM optical transmitter technology to be developed in this program is a long-range Free Space Optics (FSO) link for Interplanetary Optical Telecommunications supporting robotic explorers. The second planned products will be FSO links for NASA satellite-to-ground applications as well as intersatellite communications. Subsequent products will be for air-to-ground, air-to-air, and ground-to ground communications.

Non-NASA Applications

Commercial lasercomm links—both intersatellite, and terrestrial. Air-to-air and air-to-ground applications in the Unmanned Aerial Vehicles applications.

Identification and Significance of Innovation

We propose an innovative resonantly pumped Er-based 1550-nm laser transmitter suitable for PPM for deep space communications. Resonantly pumped Er lasers provide for high optical conversion efficiency, which coupled with high-efficiency pumping using highly efficient diode pump lasers at 1480 nm can lead to unprecedented wallplug efficiencies for these lasers.

We will use a novel diode laser pumped, actively Q-switched solid-state laser architecture. Our unique approach, of optimizing the diode pump laser design to the Er cavity design, will allow us to extract maximum efficiency from the system (greater >25%). This is a unique laser, not available on the market. Using our miniature communications module background and commercial products, we intend to integrate this solution in a minimum footprint possible, minimizing the size, weight and power (SWaP) and launch costs.

Estimated technology readiness levels (TRLs) at beginning and end of contract

- 3
- 6

20-W HIGH-EFFICIENCY 1550-nm PULSED FIBER LASER

PolarOnyx, Inc.

2014 Phase I
H9.02-9962

Identification and Significance of Innovation

A pulse shaping and spectral shaping 20 W high-efficiency (>25%) short pulse fiber laser is introduced for the first time to meet the needs of deep space communications. The innovations are

- Pulse shaping technique to obtain >45 dB extinction ratio shaped pulses with <35 ps rise/fall time
- Spectral shaping technique to obtain transform limited spectrum and high optical signal to ratio (OSNR).
- Pulse shaping technique to mitigate non-linear effects such as stimulated Brillouin scattering (SBS).
- State-of-the-art fiber amplifier, electronics, and thermal management technique to achieve compact 20-W fiber laser original equipment manufacturer (OEM) module with >25% wallplug efficiency.

PolarOnyx has been leading both the R&D and commercial production in the world. We have recently commercialized the highest energy (0.5 mJ) fs fiber laser product and won 2014 Prism Award Finalist (category of industrial lasers). We are confident that the proposed short pulse fiber laser will be accomplished in both scientific breakthrough and commercialization.

Estimated technology readiness levels (TRLs) at beginning and end of contract

- 3
- 6

Technical Objectives

- Study and apply the pulse shaping technique to achieve short pulse operation with the required wave format (<35 ps rise/fall time). In cooperating with our pulse shaping technology and successful experience in developing high efficiency and high power short pulse fiber lasers, a proof-of-concept demonstration for a 10-W fiber laser will be given.
- Investigate pulse interaction with nonlinear media and pulse/spectral shaping effects of the proposed short pulse fiber laser. Design and select FBG and EYDF to achieve higher power conversion efficiency, mitigate nonlinear effects, and correct pulse distortion and modulation chirp.
- Investigate high-speed electronics for processing and synchronization, protocol interfaces, and radiofrequency signal generation for the modulator. Design radiation hardness electronics for both high-speed electronics and high-power diode drivers.

NASA Applications

In addition to NASA's deep space communications, the proposed short pulse high-power fiber laser approach can also be used in other applications, such as space, aircraft, and satellite applications of Laser Detection and Ranging (LADAR) systems and communications. PolarOnyx will develop a series of products to meet various requirements for NASA/military deployments.

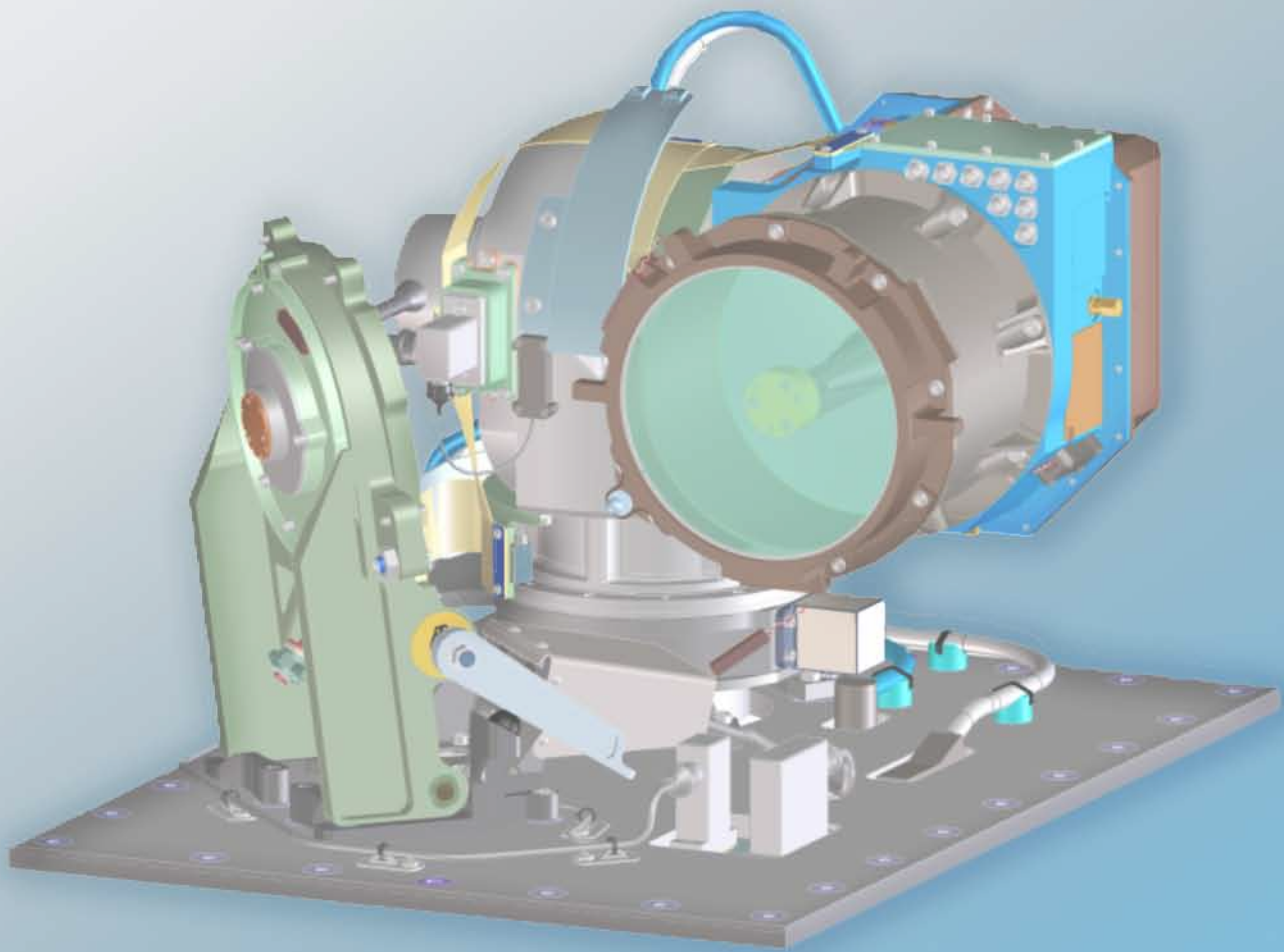
Non-NASA Applications

High-power fiber lasers represent the next generation of critical optical components needed to build the coherent optical communications of the future and cable TVs that will deliver increased communication bandwidth and improved Quality of Service (QoS) end users. The market for the application is growing and will be of great potential of hundreds of millions market.

OPTICAL COMMUNICATION TECHNOLOGY

SBIR PHASE II AWARDS

2005 TO 2012

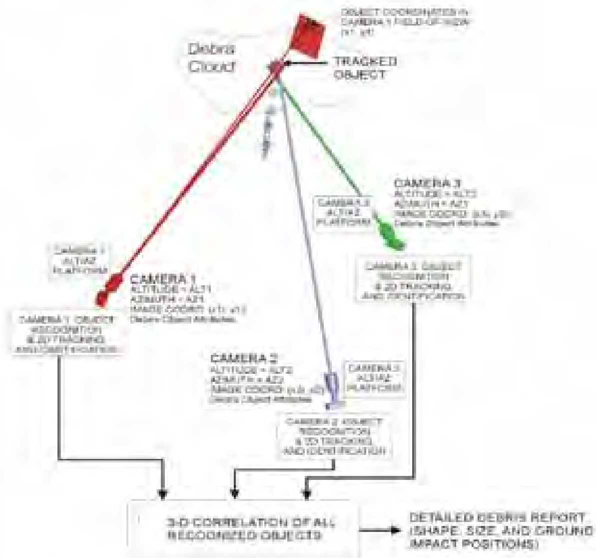


Optical Module for Space

ADVANCED AUTOMATED DEBRIS TRACKING AND RECOGNITION SYSTEM

OPTRA, Inc.

2005 Phase II
02.01-7854



Identification and Significance of Innovation

This program concerns the development of a digital imaging and tracking capability with two primary goals: (1) to provide the means for tracking and predicting the trajectories of multiple objects following the breakup of a launched space vehicle and (2) to provide a means for identifying such objects by shape and 3D size parameters.

Providing a detailed report that details shape, size, and ground impact positions for each piece of a debris cloud minutes after the failure occurs significantly increases NASA's current capabilities during search and recovery efforts following a launch failure. The innovation lies both in the use of a state-of-the-art optical system to carry out a task previously performed by radar and in the tracking and identification algorithms being developed.

Technical Objectives

The goal of the Phase II effort is to continue the development of the detection, tracking, and identification algorithms, design and build a prototype system utilizing commercial-off-the-shelf (COTS) components, and test the system with representative scenarios.

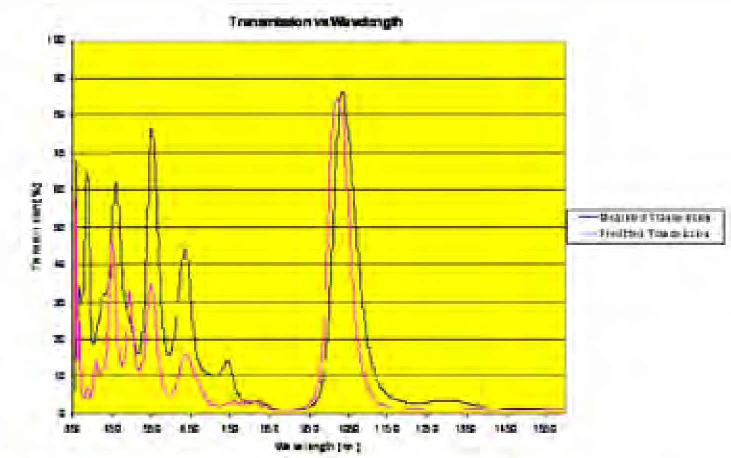
- Review/refine/improve each step in the current algorithmic process for detection, tracking, and identification.
- Develop and build a complete system architecture using COTS component.
- Fuse data from two or sensor to produce three-dimensional (3D) object trajectories and ground impact points in GPS coordinates.
- Field test the system at OPTRA and at NASA.

NASA and Non-NASA Applications

This program has a clear and immediate NASA application: to establish 3D trajectory and shape/size information for search and recovery efforts following a launch failure.

The system is applicable to Department of Defense (DoD) in weapons testing applications and to the DoD and commercial aircraft manufacturers for monitoring test flights of manned and unmanned aircraft.

VERY LARGE SOLAR REJECTION FILTER FOR LASER COMMUNICATION



Induced Transmission Filter For Laser band pass

Surface Optics Corporation

2007 Phase II
01.08-8373

Technical Objectives

- Fabricate 2-m filter with good coating adhesion at all positions on coated surface.
- Develop n,k data for selected materials out to 1.1-meter radius.
- Gain fundamental understanding of the effect of ionized gas on coating adhesion to the polymer membrane.
- Build and test coating designs on subscale membranes.
- Apply multilayer design to 2-meter substrates.

NASA and Non-NASA Applications

- Long-range laser communications; interplanetary missions
- Solar cover for laser communication receiver on defense satellite

Identification and Significance of Innovation

Surface Optics Corporation will develop a band-pass filter comprising a visible dielectric mirror and an induced transmission filter, applied to two sides of a cast polyimide membrane. The mirror/filter combination will block 95% of the incident solar radiation, while allowing a narrow pass-band for laser communication.

Expected technology readiness level (TRL) at the end of Phase I contract

- 6

HIGH-BANDWIDTH PHOTON-COUNTING DETECTORS WITH ENHANCED NEAR-INFRARED RESPONSE

aPeak, Inc.

2008 Phase II
01.06-9563

Example of the of the detector array with ROIC integrated in Phase I prototypes. The center package contains the photon counting array mounted in flip-chip and the side die is the ROIC array. Phase II will result in 32x32 pixel detector arrays mounted in flip-chip onto the ROIC array.

Identification and Significance of Innovation

Newest designs in long-range optical communication systems require high-gain, photon-counting arrays operated with high detection efficiency, outstanding temporal resolution, and capability to handle high photon detection rates. We propose to develop a novel large area, silicon photon-counting detector array in near infrared, operated with moderate cooling, high detection efficiency, high saturation counting rate, and capable of 500 ps timing resolution. Detector and readout circuit design will be improved to meet the detection efficiency, noise, timing resolution, and linearity requirements of the application.

Expected technology readiness level (TRL) at the end of the contract

- 4

Technical Objectives

- Development of the integrated electronics to perform counting, afterpulsing control and high-resolution functions and data out control
- Development of the hardware and tuning procedures of the cavity resonance at the target wavelength (1050, 1060, or 1064 nm as per input from JPL)
- Seamless process integration of DBR, flip-chip steps into the process flow
- RC–GPD array design, fabrication, and qualification

Work Plan

- Task 1: Readout integrated circuit (ROIC) array design and simulation
- Task 2: RC–GPD array design and simulation
- Task 3: Array fabrication plan

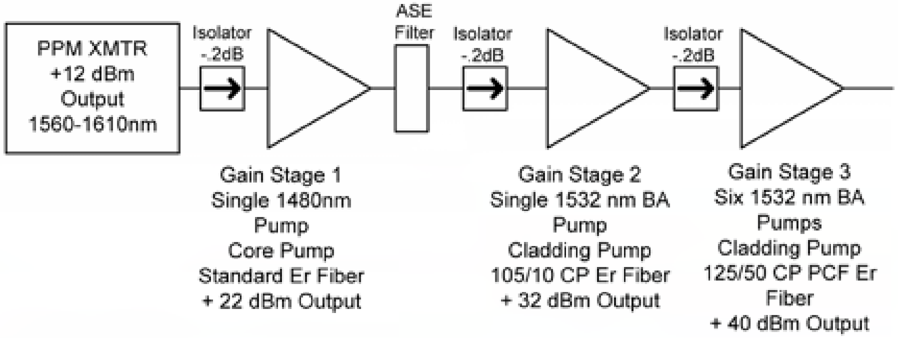
NASA and Non-NASA Applications

The novel photon counting array will find application in free space optical communications, space-ground optical links, detection or imaging in media with high turbidity, interferometry, mapping, robotic vision, very high-resolution three-dimensional (3D) imaging, hyperspectral imaging, and space docking. In addition to long-range optical communications, larger arrays could be fabricated for single-photon imaging in the infrared and visible with applications to security cameras, imaging of noncooperative targets, single-molecule detection, integration into microfluidic devices, biochips for biomedical applications, fluorescence correlation spectroscopy, etc.

HIGH-EFFICIENCY, HIGH-POWER LASER TRANSMITTER FOR DEEP SPACE COMMUNICATION

Vega Wave Systems, Inc.

2008 Phase II
01.06-9602



Technical Objectives

- Design, fabricate, and characterize a wavelength-stabilized pump source for resonant pumping in the 1430 to 1530 nm Er+-doped absorption band
- Design and fabricate an Er+-doped Master Oscillator Power Amplifier (MOPA) to achieve 1 kW peak pulse power

Work Plan

- Wavelength-stabilized pump lasers
- Design, fabricate, and characterize pump source for resonant pumping in the 1430 to 1530 nm range using proprietary technology
- Fabricate the Er+-doped MOPA to achieve 1 kW peak pulse power at 1560 nm.

NASA Applications

High-speed, high-power pulse position modulation optical communications links for deep space applications

Non-NASA Applications

- Eye safe pulsed fiber-laser-based sources for material processing and other scientific applications
- High power wavelength-stabilized pump sources at long wavelengths

Identification and Significance of Innovation

We propose improvements to fiber MOPA transmitters for deep space communications links using several new techniques:

- Operating wavelength of 1560 nm reduces the size and weight of the optical components
- Resonant pumping in the 1430-to 1530-nm band improves pump absorption and, hence, wall plug efficiency
- Wavelength-stabilized laser (WSL) pump sources: eliminates power-hungry thermoelectric (TE) coolers, producing a significant improvement in wall plug efficiency
- Photonic Crystal Fiber amplifiers improve the efficiency of the system

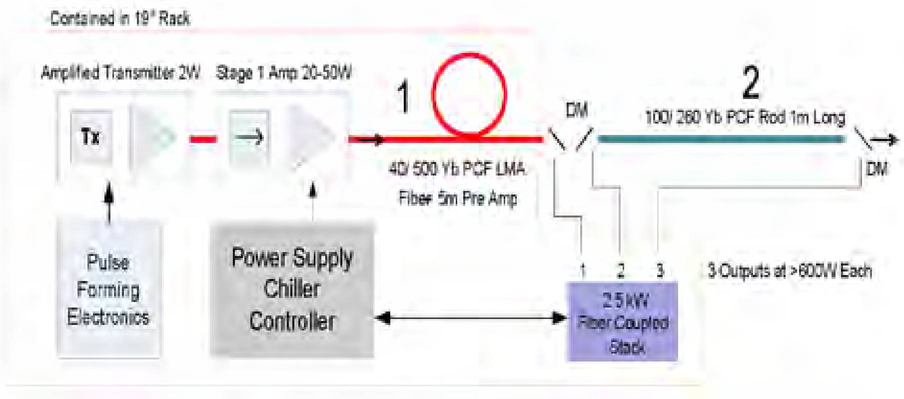
Expected technology readiness level (TRL) at the end of the contract

- 4

HIGH-POWER UPLINK AMPLIFIER FOR DEEP SPACE COMMUNICATION

Optical Engines, Inc.

2009 Phase II
01.06-8122



Identification and Significance of Innovation

We propose improvements to fiber Master Oscillator Power Amplifier (MOPA) uplink power amplifiers for deep space communications links using several new techniques:

- 2.5-k W multi-fiber coupled laser diode stack technology adapted to pumping fiber lasers and amplifiers
- Efficient Etched Air Taper Combiners allow for integration of high pump powers into fiber based amplifiers and Lasers
- PCF amplifiers provide high peak power operation while also providing for high average power operation
- A hybrid amplification system that uses both coiled and rod-type PCFs

Expected technology readiness level (TRL) at the end of the contract

- 4

Technical Objectives

- Design, fabricate, and characterize a coiled and rod-type photonic crystal fiber (PCF) amplifier and compare its performance to requirements.
- From the results obtained from both amplifiers, design, fabricate, characterize, and deliver an uplink transmitter channel that meets or exceeds the current requirements for integration into existing NASA uplink testbed infrastructure.

Work Plan

- Design high peak power fiber amplifiers
- Design, fabricate, and characterize both a coiled and rod-type PCF-based amplifier and compare under worst case operational scenarios
- Fabricate and deliver an uplink transmitter meeting the current proposed requirements

NASA Applications

High-speed, high-power pulse position modulation optical communications links for deep space applications Light Detection and Ranging (LIDAR) and remote sensing applications.

Non-NASA Applications

- Pulsed fiber-laser-based sources for material processing and other scientific applications
- Directed energy applications

HIGH-PERFORMANCE NEGATIVE-FEEDBACK NEAR-INFRARED (NIR) SINGLE-PHOTON COUNTING DETECTORS AND ARRAYS

Amplification Technologies, Inc.

2009 Phase II
01.06-8219

Technical Objectives

- Develop the internal discrete amplification design in InGaAs/InP material system to achieve stated goals.
- Develop the design of the detector array that meets or exceeds the desired performance characteristics.
- Develop fabrication processes for the fabrication of the internal discrete amplifier detectors and arrays.
- Fabricate, test, and analyze the results of the fabricated devices.
- Deliver fully functional InGaAs/InP-based photodetectors and arrays with internal discrete amplification to NASA at the onclusion of Phase II.

NASA and Non-NASA Applications

- Long-range space-to-ground communication links
- Intersatellite links
- Earth orbiting to ground optical communication
- Quantum cryptography
- Three-dimensional (3D) imaging
- Night vision

NASA and Non-NASA Applications

- Optical communication
- Light Detection and Ranging/Laser Detection and Ranging (LIDAR/LADAR) remote sensing

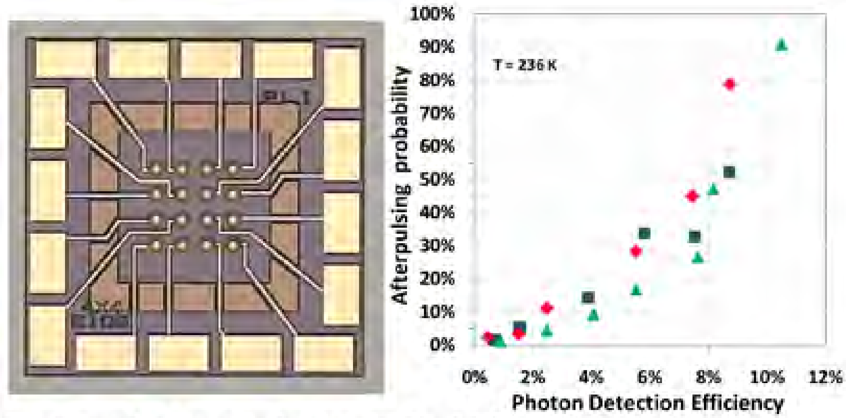
Identification and Significance of Innovation

New photon-counting photodetectors and arrays are proposed to advance the state of the art in long-range space optical communications. The proposed detector operates at 1000 nm to 1600 nm wavelengths and have high detection efficiency, low jitter, high bandwidth, very high internal gain, and extremely low excess noise. The detector design will be based on the invented breakthrough technology of discrete amplification. The new detector enables meeting the goals of long-range space optical communication applications.

NEGATIVE FEEDBACK AVALANCHE DIODE (NFAD) ARRAYS FOR SINGLE-PHOTON OPTICAL COMMUNICATIONS AT 1.5 mm

Princeton Lightwave, Inc.

2009 Phase II
01.06-9687



Photograph of proof-of-concept 4 x 4 NFAD array to be scaled to 128 x 128 in proposed program and Phase 1 data for self-quenching NFAD integrated afterpulsing at detection efficiencies of up to ~10%.

Identification and Significance of Innovation

We propose to develop large-format 128 x 128 single-photon counting detector arrays suitable for deployment in spacecraft terminal receivers supporting long-range laser communications. We will leverage initial success in monolithically integrating "negative feedback" elements with state-of-the-art single-photon avalanche diodes to realize large-scale NFAD arrays in which array pixels have good detection efficiency, low dark count rate, low afterpulsing, low timing jitter, and high counting rate. Since NFADs self-quench and self-arm, they can be implemented with greatly simplified backend circuitry and enable single-photon sensitive focal plane arrays with vastly reduced single-photon sensitive focal plane arrays with vastly reduced complexity relative to the state-of-the-art. NFAD arrays have significant promise for enabling space-qualifiable focal plane arrays that serve applications requiring 1.5 µm single photon detection.

Expected technology readiness levels (TRLs) at start and end of contract

- 2
- 4

Technical Objectives

- Optimize pixel-level NFAD design.
- Implement optimized pixel-level NFADs into large-format arrays.
- Develop characterization capability for testing large-format NFAD arrays (i.e., 128 x 128 x 100 µm pitch).

Work Plan

- NFAD wafer epitaxial design and fabrication
- NFAD 32 x 32 array-level design and photomask fabrication
- NFAD 32 x 32 array wafer processing and wafer-level testing
- Design of fan-out board test platform
- Test electronics development, including FPGA and test code
- NFAD 32 x 32 array prototype characterization
- Second iteration of A.1 to A.6 for 128 x 128 NFAD format
- Summarize results and define inputs for full FPA development

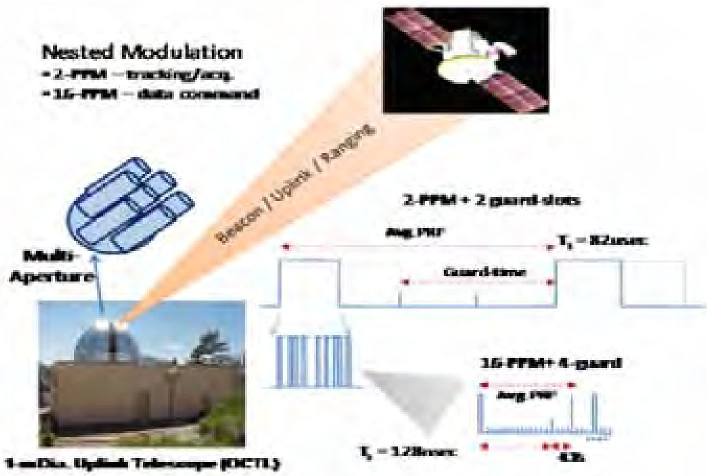
NASA Applications

- Free-space optical communications, including space-based laser communications links
- Active remote sensing optical instruments Light Detection and Ranging (LIDAR)

Non-NASA Applications

- Range-finding and LADAR applications
- Commercial Laser Detection and Ranging (LADAR) systems
- Free space optical (satellite) communications
- Single photon counting for fluorescence, photoluminescence, and photoemission applications

MULTI- kW UPLINK FIBER-LASER BEACON WITH AGILE SIGNAL FORMAT



Fibertek, Inc.

2010 Phase II
01.04-9435

Technical Objectives

- High-efficiency Yb-fiber amplifiers of Pavg~500 W, with high spectral responsivity Si-APD photon-counting detectors
- Fiber master-oscillator power-amplifier (fiber MOPA) design, with tailored spectral and temporal characteristics of near-diffraction limited beam-quality (M2<1.5)
- Wide range repetition-rates and pulse-pattern/formats capability, like the two-level nested pulse position modulation (PPM) desired for an uplink laser beacon.
- Design is aided by comprehensive fiber MOPA simulation tool, robust “all-fiberoptic” design, with no laser alignment requirements
- Operate with electro-optic power efficiency (estimated >25%). Modular architecture scalable to a temporally synchronized, multi-aperture configuration

Work Plan

- Reconfigure power amplifier from a free-space signal coupled to an all-fiber form, leading to an all-fiber implementation of the laser channel
- Average and peak power at 1030-nm to 500 W under 500 kHz PPM-16 ary operation
- Improve multistage seed amplifier chain
- Design, build, test, and deliver prototype hardware

NASA Applications

- Compact high-efficiency 1030-nm laser transmitter for deep-space communication
- Low power uplink laser beacons for near-Earth optical communication links, or, smaller aperture optical telescopes (~30-cm) to enable high-bandwidth optical links

Non-NASA Applications

Laser illuminator for directed-energy (DE) applications. MDA applications for target identification and designation.

Identification and Significance of Innovation

Laser beacons with scalable powers are needed for ground to deep space optical communication uplinks. They serve as absolute reference for tracking of spacecraft during the downlink laser communication. For such space communication link distances the beam spread due to diffraction is significant enough that only few photons are collected by a moderate size optical telescopes on the spacecraft. This necessitates photon-counting detectors suited for the space environment, along with increasing the output power of the laser beacon. Ultralow noise silicon avalanche photodetector (Si-APD) based position-sensing detectors are used on the spacecraft to detect the laser beacons. Such Si-APDs are also radiation-hardened and compatible with space-environment operation. It is therefore desirable to operate at shorter wavelengths ~1000 nm, where Si-APDs have improved spectral responsivity. This helps to improve the SNR for tracking, and consequently reduce the uplink laser power requirements.

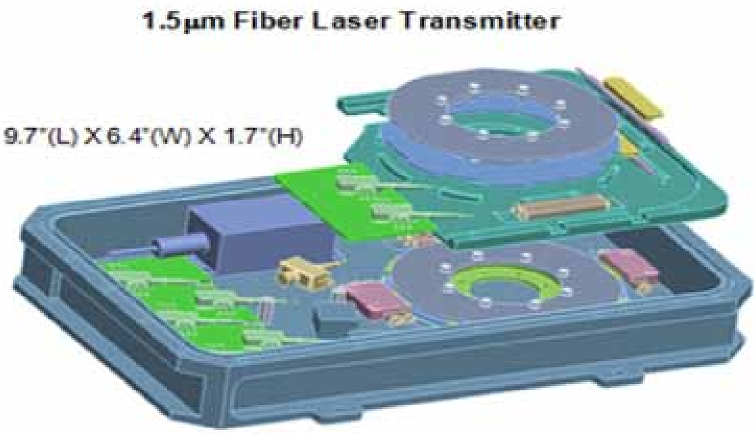
Estimated technology readiness levels (TRLs) at beginning and end of contract

- 3
- 5

DOWNLINK FIBER LASER TRANSMITTER FOR DEEP SPACE COMMUNICATION

Fibertek, Inc.

2011 Phase II
01.04-9718



Identification and Significance of Innovation

NASA's Space Communications and Navigation (SCaN) roadmap, calls for an integrated network approach to communication and navigation needs, from near-Earth to planetary missions. Laser-based optical communication links for space provides an order of magnitude higher data rates than corresponding radiofrequency links. In addition, due to much smaller size, weight and power burden to spacecraft, resources are available to enhance or extend science missions. Tremendous progress made in 1.5 um and 1-um fiber laser/amplifier technologies, their power scaling, and availability of reliable high-power components, makes such transmitters feasible for space mission. In this Small Business Innovation Research (SBIR) proposal, we propose to develop 1.5-um fiber-amplifier-based laser transmitters, with Pav>4 W, and compatible with a variety of M-ary PPM formats that have a clear path to a space-qualification roadmap. In addition, power-scaling to 10 W, a thermal operation over temperature range and improved power efficiency are addressed. Limited scope qualification tests are also planned.

Estimated technology readiness levels (TRLs) at beginning and end of contract

- 4
- 6

Technical Objectives

Proposed program objective: design, build, and test a technology readiness level (TRL) 6 quality laser and conduct NASA GEVs vibration and thermal vacuum testing to validate the design. Phase 1 experimental results demonstrates that the laser complies with Jet Propulsion Laboratory (JPL) specified M-ary pulse-position-modulation (PPM) variable formatting with peak powers >640 W over 10C-50C. Due to planetary lasercom demonstration mission being the target application, the design is based on the use of mature and high-reliability 1.5-um fiber-optic component technology and a fiber-amplifier architecture consistent with a space qualification roadmap.

Work Plan:

- Complete Optical Design Trade Studies: Finalize the optical design and improve efficiency.
- Design Flight Quality Transmitter Package: A comprehensive optical, thermal, mechanical, electrical design.
- Mission Assurance: Continue reliability assessments and optical parts Improvements from phase I TVAC test parts.
- Fabricate a flight-like prototype. A full-scale laser transmitter will be built and performance tested.
- TRL 6 Testing: The laser will be vibration and thermal vacuum tested to NASA GEVs levels.

NASA Applications

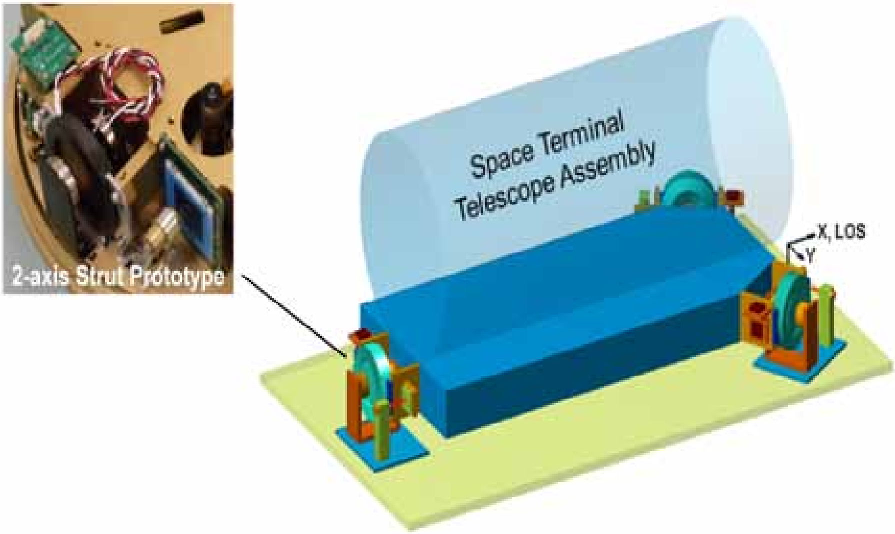
High bandwidth lasercom flight terminal for planetary missions, as well as for lunar and Mars relay links.

- Space-qualifiable, robust, compact, and efficient Light Detection and Ranging (LIDAR) component, e.g., CO_2 sensing, pumping optical parametric oscillator/optical parametric amplifier (OPO/OPA) for a mid-infrared LIDAR source.
- Coherent LIDAR component technology for aviation-safety sensor, e.g., wind-shear/turbulence, wake-vortex hazard, etc.

Non-NASA Applications

- High-bandwidth low-Earth-orbit/geostationary-Earth-Orbit (LEO/GEO) satellite communication for military
- High-bandwidth real-time feed from multiple unmanned aerial vehicles (UAVs), via LEO/GEO crosslinks
- High-bandwidth GEO crosslinks for commercial satcom.

ISOLATION PLATFORM FOR LONG-RANGE OPTICAL COMMUNICATIONS



Controlled Dynamics, Inc.

2012 Phase II
H9.01-9372

Technical Objectives

Compact, Lightweight Isolation Platform (CLIP) concept was developed to measure and establish the feasibility to meet space terminal isolation requirements. Sensor and actuator component testing have further demonstrated design at technology readiness level (TRL) 4.

Phase II goals are to ground test an end-to-end prototype on a soft suspension testbed to demonstrate performance in a simulated low-g operational environment. Both search and beacon track will be demonstrated. Environment testing iterations will be performed to produce space qualified two-axis strut assemblies for delivery to NASA. Three-strut assemblies rigidly mounted to any space terminal will provide 6 degrees of freedom (DOF) isolation and high-bandwidth stabilization. These struts are designed for robustness and can be used as add-on to any rigid structure, thus enabling a broad range of space applications requiring high-precision stabilization, isolation, and pointing.

NASA Applications

- Deep Space Planetary Missions (e.g., Mars 2020)
- Deep Space Optical Terminal (DOT) Project
- Space Communications and Navigation (SCaN) Program
- Integrated Radio and Optical Communications (iROC) Project
- Alternative for Laser Communications Relay Demonstration (LCRD) Mission
- Upgrade for Optical Payload for LAsercomm Science (OPALS)

Non-NASA Applications

The two-axis isolation struts technology broadly is applicable to a wide range of vehicles including orbital RLVs, Earth-orbiting satellites, and deep space vehicles.

Identification and Significance of Innovation

Optical communication links provide higher data transfer rates with lower mass, power, and volume than conventional radiofrequency links. For deep space applications at long operational ranges, high-performance stabilization of the space terminal data link is required. To meet this need, Controlled Dynamics Inc., has developed a novel application of our free-floating isolation platform. Based upon a shuttle-proven technology, this approach yields 6 DOF isolation from the disturbances of the host vehicle while providing high-bandwidth active stabilization to attenuate both payload disturbances as well as any residual disturbances transferred from the base across the power/data umbilical. The proposed approach is designed to achieve better than 0.5 microradian-rms stabilization for all frequencies above 0.1 Hz when operating in a space environment.

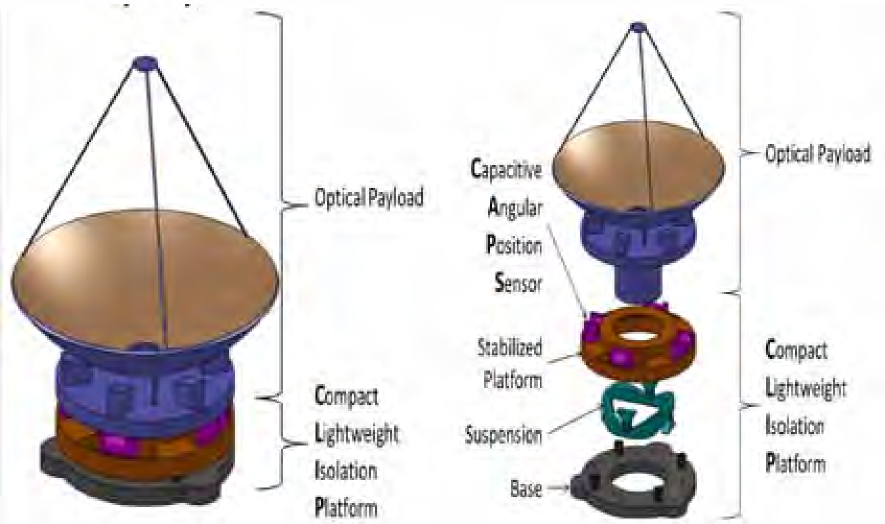
Estimated technology readiness levels (TRLs) at beginning and end of contract

- 4
- 6

COMPACT, LIGHTWEIGHT ISOLATION PLATFORM (CLIP)

Applied Technology Associates

2012 Phase II
H9.01-9621



Identification and Significance of Innovation

NASA has a critical need for improved bidirectional data transmission rates from a variety of spacecraft to Earth. NASA estimates that the current Mars-to-Earth transfer rate of 6 Mbps might be increased to 600 M bps using a laser communication (LC) system. Beam jitter caused by spacecraft-based motion must be reduced to submicroradian levels to enable beaconless optical beam pointing. ATA will create a CLIP that will provide a stabilized platform to prevent the 150-microradian spacecraft disturbance environment from reaching the LC terminal. To enable that stabilization, ATA will develop an ultra low angular noise CAPS. CAPS will have low-power and high reliability, which ATA will demonstrate by producing prototypes in Phase I and a CLIP EDU in Phase II. ATA will develop the CLIP, a 0.5 microradian residual motion stable platform, for programs like iROC.

Estimated technology readiness levels (TRLs)at beginning and end of contract

- 4
- 5

Technical Objectives

- Fine-tune Capacitive Angular Position Sensor (CAPS) sensor electronics and measure sensor noise
- Incorporate lessons learned from the CAPS prototype build/test into an updated CAPS design for use on the Compact, Lightweight Isolation Platform (CLIP)
- Design, build, and test the improved CAPS sensors
- Design an engineering development unit (EDU) CLIP platform that will interface to a commercial off-the-shelf (COTS) control/ drive system
- Build the CLIP EDU
- Test the CLIP EDU in a quiescent environment and a representative vibration environment

The goal is to produce a stable platform that can host laser communication payloads by reducing 150 micro-rad spacecraft jitter down to 0.5 micro-rad. Phase I, will produce a low frequency CAPS design at technology readiness level (TRL) 4. Ph II plans to build a CLIP and EDU to support long-range optical communications in space.

Work Plan

CAPS prototype characterization; build a third sensor using alternate potting material; build a final version for CLIP assembly. Perform assembly integration and test. Complete detailed CLIP design and build and test a completed CLIP platform.

NASA Applications

Applied Technology Associates (ATA) developed CLIP concept is the basis for NASA's laser communication terminal for the LLCD and LCRD programs. ATA's proposed CLIP and CAPS may support NASA integrated Radio and Optical Communications (iROC) project's laser collimator.

Non-NASA Applications

Air Force's Space Laser Communication Terminal (SLCT), DARPA's Laser Weapon System Module (LWSM), Lockheed Martin's Space Optical Tracking (SpOT), Navy's Laser Weapon System (LaWS), and Marine's Ground Based Air Defense (GBAD).

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