NASA SBIR 2020 Phase I Solicitation

H9.01 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

Technology Area: TA5 Communication and Navigation

Scope Title

Free-Space Optical Communications Technologies

Scope Description

This Free-space Long Range Optical Communications subtopic seeks innovative technologies for advancing free-space optical communications by pushing future data volume returns to and from space missions in multiple domains with return data-rates > 100 Gbit/s (cis-lunar, i.e. Earth or lunar orbit to ground), > 10 Gbit/s (Earth-sun L1 and L2), >1 Gbit/s per AU-squared (deep space), and >1 Gbit/s (planetary lander to orbiter) and forward data-rates > 25 Mb/s at ranges extending from the Moon to Mars. Innovative technologies should target improved efficiency, reliability, robustness, and longevity for existing or novel state-of-the-art flight laser communication systems. Photon-counting sensitivity, near infrared (NIR), space-flight worthy detectors/detector arrays for supporting laser ranging for potential navigation and science are of particular interest. Ground-based technologies targeting high power, NIR and intensity-modulated lasers with fast rise times and low timing jitter (sub-nanosecond) are needed to support high forward data-rates and laser ranging.

Proposals are sought in the following specific areas:

<u>Flight Laser Transceivers</u>

Low-mass, high-Effective Isotropic Radiated Power (EIRP) laser transceivers for links over planetary distances with:

- 30 to 50 cm clear aperture diameter telescopes for laser communications
- Targeted mass of opto-mechanical assembly per aperture area, less than 100 kg/square-meter
- Cumulative wave-front error and transmission loss not to exceed 2 dB.
- Advanced thermal-mechanical designs to withstand planetary launch loads and flight temperatures by the optics and structure, at least -20° C to 70° C operational range
- Design to mitigate stray light while pointing transceiver 3 degrees from edge of sun
- Survive direct sun pointing for extended duration

Transceivers fitting the above characteristics should support robust link acquisition tracking and pointing characteristics, including point-ahead implementation from space for beacon assisted and/or "beaconless" architectures. Innovative solutions for mechanically stiff, light-weighted thermally stable structural properties are sought.

- Pointing loss allocations not to exceed 1 dB (pointing errors associated loss of irradiance at target less than 20%)
- Receiver field-of-view of at least 1 milliradian angular radius for beacon assisted acquisition, tracking and pointing
- As a goal additional focal plane with field-of-view to support on-board astrometry is desired
- Beaconless pointing subsystems for operations beyond 3 AU
- Assume integrated spacecraft micro-vibration angular disturbance of 150 micro-radians (<0.1 Hz to ~500 Hz)

Low complexity small footprint agile laser transceivers for bi-directional optical links (> 1-10 Gbit/second at a nominal link range of 1000-20000 km) for planetary lander/rover to orbiter and/or space-to-space cross links.

- Disruptive low Size, Weight and Power (SWaP) technologies that can operate reliably in space over extended mission duration
- Vibration isolation/suppression systems that will integrate to the optical transceiver in order to reject high frequency base disturbance by at least 50 dB
- Desire integrated launch locks and latching mechanism
- Low burden (mass, power, volume)
- Robust for space flight
- Should afford limited +/- 5 mrad - +/-12 mrad actuated field-of-regard for the optical line of sight of the transceiver

<u>Flight Laser Transmitters</u>

High-gigabit/s laser transmitters

- 1550 nm wavelength
- Lasers, electronics and optical components ruggedized for extended space operations
- High rate 10-100 Gb/s for cis-lunar
- 1 Gb/s for deep-space
- Integrated hardware with embedded software/firmware for innovative coding/modulation/interleaving schemes that are being developed as a part of the Consultative Committee for Space Data Systems (CCSDS)

High peak-to-average power laser transmitters for regular or augmented M-ary PPM modulation with M=4, 8, 16, 32, 64, 128, 256 operating at NIR wavelengths, preferably 1550 nm with average powers from 5 - 50 W

- Sub-nanosecond pulse
- Low pulse jitter
- Long lifetime and reliability operating in space environment (> 5 and as long as 20 years)
- High modulation and polarization extinction ratio with 1-10 GHz line width

Space-qualifiable wavelength division multiplexing transmitters and amplifiers with 4 to 20 channels and average output power > 20W per channel; peak-to-average power ratios >200; >10 Gb/s channel modulation capability.

- >20% wall-plug efficiency (DC-to-optical, including support electronics) with description of approach for stated efficiency of space-qualifiable lasers. Multi-watt Erbium Doped Fiber Amplifier (EDFA), or alternatives, with high gain bandwidth (> 30nm, 0.5 dB flatness) concepts will be considered.
- Radiation tolerance better than 50 krad is required (including resilience to photo-darkening).

<u>Receivers/Sensors</u>

Space-qualifiable high-speed receivers and low light level sensitive acquisition, tracking, pointing, detectors, and detector arrays

- NIR wavelengths: 1064nm and/or 1550 nm
- Sensitive to low irradiance incident at flight transceiver aperture (~ fW/m2 to pW/m2) detection
- Low sub-nanosecond timing jitter and fast rise time
- Novel hybridization of optics and electronic readout schemes with in-built pre-processing capability
- Characteristics compatible with supporting time-of-flight or other means of processing laser communication signals for high precision range and range rate measurements
- Tolerant to space radiation effects, total dose > 50 krad, displacement damage and single event effects

Novel technologies and accessories

Narrow Bandpass Optical Filters

- Space-qualifiable, sub-nanometer to nanometer, noise equivalent bandwidth with ~90% throughput, large spectral range out-of-band blocking (~ 40 dB)
- NIR wavelengths from 1064 – 1550 nm region, with high transmission through Earth's atmosphere
- Reliable tuning over limited range

Novel Photonics Integrated Circuit (PIC) devices targeting space applications with objective of reducing size, weight and power of modulators, without sacrificing performance. Proposed PIC solutions should allow improved integration and efficient coupling to discrete optics, when needed.

Concepts for offering redundancy to laser transmitters in space

- Optical fiber routing of high average powers (10's of watts) and high peak powers (1-10 kW)
- Redundancy in actuators and optical components
- Reliable optical switching

Ground Assets for Optical Communication

Low cost large aperture receivers for faint optical communication signals from deep space subsystem technologies:

- Demonstrate innovative subsystem technologies for >10 m diameter deep-space ground collector
- Capable of operating to within 3 degrees of solar limb
- Better than 10 micro radian spot size (excluding atmospheric seeing contribution)
- Desire demonstration of low-cost primary mirror segment fabrication to meet a cost goal of less than $35 K per square meter
- Low-cost techniques for segment alignment and control, including daytime operations
- Partial adaptive correction techniques for reducing the field of view required to collect signal photons under daytime atmospheric "seeing" conditions
- Innovative adaptive techniques not requiring a wavefront sensor and deformable mirror of particular interest
- Mirror cleanliness monitor and control systems
- Active metrology systems for maintaining segment primary figure and its alignment with secondary optics
- Large core diameter multi-mode fibers with low temporal dispersion for coupling large optics to detectors remote (30-50 m) from the large optics

1550 nm sensitive photon counting detector arrays compatible with large aperture ground collectors with a means of coupling light from large aperture diameters to reasonably- sized detectors/detector arrays, including optical fibers with acceptable temporal dispersion

- Integrated time tagging readout electronics for >5 giga-photons/s incident rate

- Time resolution <50 ps at 1-sigma
- Highest possible single photon detection efficiency, at least 50% at highest incident rate
- Total detector active area > 0.3 - 1 mm2
- Integrated dark rate < 3 mega-count/s.

Cryogenic optical filters

- Operate at 40 K with sub-nanometer noise equivalent bandwidths
- 1550 nm spectral region, transmission losses < 0.5 dB, clear aperture
- >35 mm, and acceptance angle > 40 milliradians with out-of-band rejection of > 65 dB from 0.4 - 5 microns.

Multi-kilowatt laser transmitters for use as ground beacon and uplink laser transmitters

- Near infrared wavelengths in 1.0 or 1.55 micrometer spectral region
- Capable of modulating with narrow nanosecond and sub-nanosecond rise times
- Low-timing jitter and stable operation
- High speed real-time signal processing of serially concatenated pulse position modulation operating at a few bits per photon with user interface outputs
- 15-60 MHz repetition rates

For all technologies lowest cost for small volume production (5 to 20 units) is a driver. Research must convincingly prove technical feasibility (proof-of-concept) during Phase I, ideally with hardware deliverables that can be tested to validate performance claims, with a clear path to demonstrating and delivering functional hardware meeting all objectives and specifications in Phase II.

References

https://www.nasa.gov/mission_pages/tdm/lcrd/index.html

https://www.nasa.gov/directorates/heo/scan/opticalcommunications/illuma-t

https://www.nasa.gov/feature/goddard/2017/nasa-laser-communications-to-provide-orion-faster-connections

https://www.nasa.gov/mission_pages/tdm/dsoc/index.html

Expected TRL or TRL range at completion of the project: TRL 2-3 Phase I for maturation to TRL 3-5 in Phase II

Desired Deliverables of Phase II

Prototype, Hardware, Software

Desired Deliverables Description

Models of components or assemblies for flight laser transceivers or Ground receivers

State of the Art and Critical Gaps

The State Of the Art (SOA) for Free-Space Optical Communications (FSOC) can be subdivided into near-earth (extending to cis- and trans-lunar distances) and planetary ranges with the Lagrange points falling in between.

Near Earth FSOC technology has completed a number of technology demonstrations from space and is more mature. Nonetheless, low size-weight power novel high speed 10-100 Gb/s space-qualified laser transmitters and receivers are sought. These transmitters and receivers can possibly be infused for deep space proximity links, such as landed assets on planetary surfaces to orbiting assets with distances of 5000-100000 km or inter-satellite links. Innovative light-weight space-qualified modems for handling multiple optical modulation schemes.

A technology demonstration for deep space FSOC is anticipated in the next decade. Critical gaps following a successful technology demonstration will be light-weighted 30-50 cm optical with a wide operational temperature range -20C to 50C over which wave front error and focus is stable. High peak-to-average power space qualified lasers with average powers of 20-50 W. Single photon-sensitive radiation-hardened flight detectors with high detection efficiency, fast rise times low timing jitter. The detector size should be able to cover 1 milliradian Field-Of-View (FOV) with an instantaneous FOV comparable to the transmitted laser beam width. Laser pointing control systems that operate with dim laser beacons transmitted from earth or use celestial beacon sources.

For Deep Space Optical Communications (DSOC) ground laser transmitters with high average power (kW class) but narrow line-widths (< 0.3 nm) and high variable repetition rates are required. Innovative optical coatings for large aperture mirrors that are compatible with near-sun pointing applications for efficiently collecting the signal and lowering background and stray light.

Relevance / Science Traceability

A number of FSOC-related NASA projects are ongoing with launch expected in the 2019-2022 time frame. The Laser Communication Relay Demonstration (LCRD) is an earth-to-geostationary satellite relay demonstration to launch in late 2019. The Illuma -T Project will extend the relay demonstration to include a Low Earth Orbit (LEO) node on the ISS in 2021. In 2022 the EM-2 Optical to Orion (O2O) demonstration will transmit data from the Orion crewed capsule as it travels to the Moon and back. In 2022 the DSOC Project technology demonstration will be hosted by the Psyche Mission spacecraft extending FSOC links to astronomical unit distances.

These missions are being funded by NASA's Space Technology Mission Directorate (STMD) Technology Demonstration Mission (TDM) Program and Human Exploration Operations Mission Directorate (HEOMD) Space Communications and Navigation (SCaN) Program.