DEMONSTRATION OF BLUE-GREEN LASER DIGITAL COMMUNICATIONS IN SPACE APPLICATIONS

Background

During the past seven years, NASA has been conducting basic research into the enhancement of high-speed data communication systems using research and development staffs at various universities around the United States. Compression and error correction algorithm enhancements applied to conventional radio frequency technologies for ultra- high frequency, super-high frequency, extremely high frequency, and microwave communications have achieved improvements of capacity in the order of 2 to 8 times currently employed capabilities. In addition, NASA has explored the potential for novel concepts and contracted with the University of Michigan to explore enhancement of light-based communication techniques using coherent and noncoherent sources. This research has identified the use of coherent light sources in the blue-green regime (520-540 nanometers) as one of the most promising new technologies. The concept demonstration employed a dye laser excimer system and a proven radar pulse coding technique to achieve up to 4.2 GB/sec data transfer rate in a half duplex mode of operation, an improvement of 12 times current capabilities. NASA would like to extend this conceptual effort to investigate the feasibility using the approach for earth orbiting spacecraft and interplanetary probes used for deep space exploration.

Prior Experimentation

The potential feasibility of blue-green excimer laser communications has been previously demonstrated in rudimentary form by DOD. The experimental applications employed large testbed aircraft and both surface and underwater detectors that demonstrated the potential for excellent atmospheric transmission and ability to provide limited penetration of shallow littoral waters. The laser technology, when tuned to a frequency of 532nm showed a distinct lack of disruption by absorption and scattering by atmospheric components, particularly the oxygen and oxygen compound components. However, this early system lacked the ability to obtain sufficient modulation needed for data communications and work was abandoned in favor of RF techniques. Published work by DOD contractors was used as a starting point for work by University of Michigan researchers.

The University of Michigan Optics Department conducted theoretical work and fabricated several small-scale desktop prototypes in 1996 to show that this system may be able to sustain data communications in the neighborhood of 12 to 15 GB per second. Using novel pulse code modulation techniques, combined with light polarization techniques originally employed for fiber optics, has demonstrated a 100-fold improvement of data transmission rates due to expanded bandwidth. The blue-green laser provides an ability to employ multiple simultaneous interleave channels on a single transmission medium.

Task Definition

The purpose of this task is to demonstrate the feasibility of using the blue-green laser system for an earth to low-earth orbiting satellite system and for interorbiting platform communications by the fabrication and operation of a prototype communication system. The task will be completed in three stages. Stage 1 will demonstrate long-range (62nm (100km)) high data rate atmospheric communications as an analogue of earth to low-earth orbit communications. Phase 2 will demonstrate high data rate uplink/downlink communication with a single, low-earth orbiter platform. Phase 3 will demonstrate long-range (1000+km), one-way high data rate laser communications between two space platforms.

Conceptual Architecture

The prototype will demonstrate the feasibility of using the unique coding and data compression algorithms in conjunction with the blue-green laser to conduct high-speed data communications between ground stations, between the ground station and an orbiting platform, and between two orbital platforms. A conceptual view of an advanced prototype architecture with an additional deep space probe is shown in Figure 1.

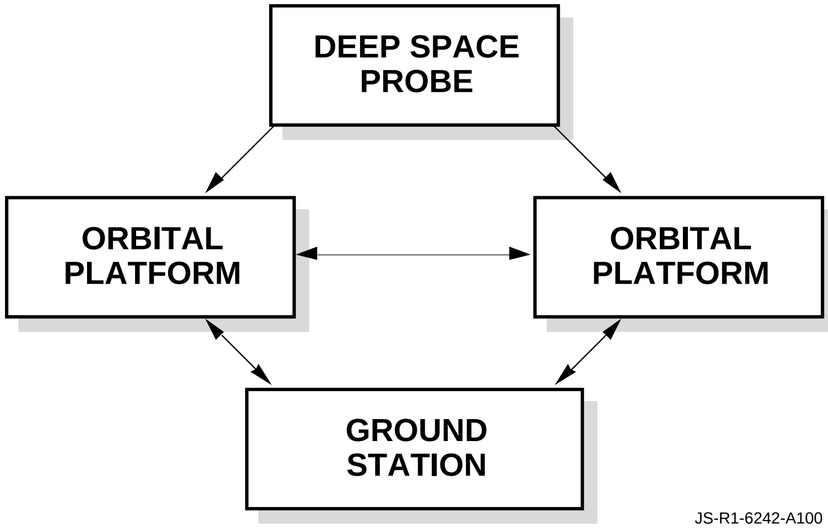

Figure 1. A Conceptual Communications Architecture for Demonstration of High Data Rate Blue-green Laser Communications

System Key Characteristics

Conceptual studies completed by systems engineering office have developed the operational requirements (shown in Figure 2) in terms of minimum acceptable performance and objective element performance to reach the full capability.

Operational Environment

Ground Station. **The ground station must be operable worldwide in a wide range of environmental conditions. Operationally, it is required to provide line-of-sight communications with an orbiting platform. The range of required atmospheric penetration will extend from directly overhead (90 degrees azimuth) to a slant range of 15 degrees above the horizon to the orbiting communication platform. The communications platform is assumed to be in low-earth orbit of approximately 130 nautical miles. The communications uplink laser will be required to achieve atmospheric penetration from the ground station through scattered cloud cover (up to 5/8 obscuration) with up to two 5,000-foot decks below 23,000 feet MSL. Communications uplink must be operable in conditions of rain (rate of up to 3 inches per hour; mass median droplet size of 2**

Key Performance Characteristic	Project Phase	Threshold Performance	Objective Performance
Data Rate (full duplex)	1	12 GB/sec	16 GB/sec
Laser Transmitter Duty Cycle	1 (ground station)	10% (transmit mode)	23% (transmit mode)
--	2,3 (Orbital transceiver)	7% (transmit mode)	14% (transmit mode)
Error Rate	1, 2, 3	< 1 per 100KB	< .1 per 100KB
Transmitter Power Consumption	1 (ground station)	8 kilowatts/hr.	5 kilowatts/hr.
--	2,3 (Orbital Transceiver	5 kilowatts/hr.	4 kilowatts/hr.
Mean Time Between Failure (MTBF)	1 (prototype ground station)	250 hours (communications operating time)	10,000 hours (communications operating time)
--	2 (orbiter-based prototype)	1000 hours	2500 hours
--	3 (orbital prototype)	3,000 hours	10,000 hours
Mean Time to Repair	1 (prototype ground station)	3 hours	1 hour
	2 (orbiter-based prototype)	2.5 hours	1.0 hours
	3 (orbital prototype)	2.0 hours	.75 hours
Mass	2 (orbiter-based prototype)	<1100 kg	< 450 kg
--	3 (orbital prototype)	< 280 kg	<200 kg
Dimensions	1 (ground stations)	NTE 40’x8’x8’ Prime mission equipment (excluding power)	20’x8’x8’ Prime mission equipment (excluding power)
--	2 (orbiter-based prototype)	8’x8’x16’ (orbiter container)	8’x8’x12’ (orbiter container)
--	3 (orbital prototype)	4.2’ radius x 8.5’ length (non-deployed canister)	4.2’ radius x 5.5’ length (non-deployed canister)

Figure 2. Operational Requirements

millimeters); snow (rate of up to 1 inch per hour, average snowflake size 1.2 centimeters); fog (ground visibility 100 meters); and blowing dust (ground visibility 100meters). Local humidity conditions for the ground communications station may range between 5 percent humidity and 100 percent relative humidity. Wind conditions will include sustained winds of 50 kts with gusts of up to 70 kts. Ground station external environment temperatures may range between minus 20 degrees Fahrenheit and 140 degrees Fahrenheit. Severe solar loading of the ground station is anticipated. Design and required sensitivity of the communications receiver is dictated by the atmospheric conditions noted in the following paragraph. The downlink receiver must be able to achieve the threshold level of sensitivity in all natural light conditions.

Orbiting Platform. The orbiting platform is required to perform in the rigors of a space environment characterized by vacuum, intense solar radiation flux, ionizing radiation, and orbital debris. The downlink to earth will be required to achieve high-integrity high-rate digital communications in a limited obscuration environment described as one-eighth scattered cloud cover with a single deck not exceeding 5,000 feet of partial cloud obscuration. Sensitivity to the uplink must accommodate communications satellites and interplanetary probe devices. The system includes light detection/signal detection devices as well as transmission devices such that the complete receive and transmit capabilities are available in the orbiting platforms. The uplink receiver must be able to achieve the threshold level of sensitivity in all encountered space light conditions. The Phase 2 orbiting platform may rely on the physical protection afforded by the shuttle orbiter; however, the Phase 3 orbiter must be designed to operate continuously in LEO for a period of three years without significant mission degradation due to natural conditions.

Planned Project Schedule

The project is to be conducted in three phases: 1) initial proof-of-concept demonstration for the earth station to a simulated lower orbiting station, 2) demonstration of ground station to orbital platform communications, and 3) demonstration of long-range orbital platform to orbital platform. In this first phase, the demonstration is intended to provide confidence in a familiar design that is capable of providing communications capabilities as described earlier with simulation of environment conditions that are provided.

Should this first phase demonstration prove successful using the blue-green laser concept and the contractor-developed pulse code modulation scheme or other data carrying scheme for digital data, NASA will continue with the second phase of the program. In the second phase, NASA will orbit a receiving-transmitting station using the shuttle orbiter to demonstrate the robustness and total capability of this communication system. NASA would like the *first* phase of the project to take *not more than 30 months.* Should the demonstration prove successful, NASA proposes that a contractor take 28 months to fabricate an initial orbiter-contained design and fabricate it for use in demonstration testing. This orbiter-contained platform will be taken into space and returned for refurbishment multiple times (5 to 7 times) over a 36-month demonstration period.

The third phase of the project is contingent on the successful completion of the first two phases. Draft designs for an independent orbital platform will be initiated during the demonstration of the Phase 2 concept, and fabrication will be initiated after successful completion of the initial orbiter tests. The orbital platform should be ready for mating to the launch vehicle 12 months after the initiation of fabrication. After launch and orbital insertion, communications tests of the orbital platform with the orbiter-based platform will continue over a 24-month period. The orbital platform will remain on station indefinitely in a dormant state without station-keeping maintenance.

Information Access and Rights

During the execution of this program, the contractor will have complete access to all research material, research prototypes, platform information, and post-closing modulation schemes used by the University of Michigan and their experiments. Contractors are free to propose any alternative means of data packing, data compression, and data rate transmission using this blue-green laser excimer system to achieve the data rates requested.

In creating this system, should it be successful, NASA will grant exclusive rights to the developer for a period of seven years from the initiation of patent or from the granting of the patent on this communication system and will hold the contractor as proprietary holder of that period. However, after the period of seven years, the patent will revert to NASA ownership for use and development in other commercial activities and will become generally commercially available to others wishing to employ this technology for advanced communications programs.

Contracting Approach

NASA proposes to execute this project using a cost plus incentive fee due to the risk expected. The total three-phase program has a not-to-exceed threshold of $225 million for contractor expenses, documentation, and other key product material that will be later described in the contract data requirements list and in the deliverable list. Phase 1 has been estimated to cost $25M; Phase 2, $95M, and Phase 3, $105M. Performance-based contracting principles will be followed in which positive performance leading to the achievement of mission objectives will be incentivized by financial means. Evaluation criteria relating to performance objectives will be specified in the Project Surveillance Plan.

NASA will execute management of this contract with insight-based methods in congruence with its performance-based contracting approach. Metrics and surveillance activities will be defined jointly by the project team from NASA and from the contractor team. NASA desires to have insight into the integrity of the process and development program to assure that true progress is indeed being made and objectives are being achieved. At the same time, NASA wishes to maintain a distance from the contractor's actual design and fabrication activities by causing no significant in-line interruptions during daily operations. However, NASA intends to conduct a critical functionally integrated program review at the critical design review. In addition, the project management organization will take on a strong partnership role during test and demonstration activities in which NASA finds itself liable or potentially liable for special coordination for the use of a laser in exoatmospheric and transatmospheric experiments, or areas in which special ranges will be required or used to demonstrate the capability of the laser's communications system. As a Governmental agency, during testing, NASA will publish notice to mariners and airmen and will execute all necessary Governmental permits related to environmental or safety integrity.

In the performance of fabrication, development, and creation of this product, NASA intends that the contractor will assume full and complete responsibility for respective health and environmental safety regulations as prescribed by the local areas where the work is conducted, respective of the U.S. Government rules and regulations in effect at the time of the effort. Transportation of the test equipment and the experimental stations will be solely the responsibility of the contractor.

Government-furnished Equipment

During Phase 1, NASA will provide a ground facility at Wallops Island, VA, of not more than 10,000 square feet, for use in the demonstration of transatmospheric communications in high humidity, fog, and obscured atmospheric environment. During this testing, NASA will provide up to 25 hours of on-station time for a high-altitude aircraft with laser receiver set to demonstrate the operations of the ground facility.

During Phase 2, the ground-to-satellite communications prototype laser will be set up in the area of the Goldstone test range in the Mojave Desert in California due to favorable atmospheric transmission conditions. During set-up testing, NASA will provide up to 5 hours of on-station time for a high-altitude aircraft with laser receiver set to verify the operations of the ground facility. NASA will orbit and operate the transceiver module for earth orbit verification of the concept. NASA will provide team members and necessary materials for integration of prototype designs for operations on the shuttle platform.

During Phase 3, NASA will accept delivery of the orbital platform for insertion into orbit. The communications system contractor has responsibility for prior designs allowing the structural, electronics. and interface integration with the launch vehicle being selected for demonstration of the concept. NASA will provide design guidelines and will assist in the coordination with the owner of the platform for these items. During the two- year inter-vehicular communications demonstration project, NASA will provide launch and refurbishment services for the shuttle-based communications platform. The contractor will operate the ground station for data collection and continuing support of refinement of communications protocols.

Contract Award Strategy

This contract will be awarded on a best-value basis in which cost, experience, technical risk, and program risk enter into a weighted evaluation formula. NASA is committed to support Federal Acquisition Regulations (FAR) and directions of Congress to enhance the position of small, disadvantaged, woman-owned companies. Thus, NASA will provide a five-preference-point differential (i.e., a positive component of five points) in the program risk category for companie meeting qualifications of a small, disadvantaged, woman-owned companies, not necessarily in the 8A and of SIC code class 4c for under 1,000 employees.

NASA is using an award scale that ranks offerors on previous experience in innovative technology application, demonstrated capability in laser and microwave communication systems, demonstrated capability for program cost control, success in research and development type of efforts, and clarity of technological approach. As part of the evaluation, cost realism will be independently assessed and scored for inclusion. In addition, NASA requests that the contractor address known risk issues in this program and provide risk mitigation strategies for what the contractor considers key mission risk areas, key performance risk areas, key technological risk areas, and/or key cost risk areas. NASA also requests the contractor identify program management metrics that the contractor will use to manage the program internally. In their proposal, bidders are asked to describe the selection of metrics, provide a rationale for use of those data elements, and identify the source of the data elements.

Delivered Items

Figure 3 identifies specific data and hardware items to be delivered during the conduct of the project.

Delivered Item	Delivery Location	Delivery verified by
Phase 1		
Ground Station	**Factory**	**DCMC -FCA/PCA**
Ground Station CDR	**Contractor Facility**	**Project Manager**
Ground Station Drawings (as designed & as built)	**NASA - GSFC**	**Project Manager / Chief Engineer**
Ground Station Design Basis Calculations	**NASA - GSFC**	**Project Manager / Chief Engineer**
Phase 2		
Orbiter-based Platform	**Factory**	**DCMC -FCA/PCA**
Orbiter-based Platform CDR	**Contractor Facility**	**Project Manager**
Orbiter-based Platform Drawings (as designed & as built)	**NASA - GSFC**	**Project Manager / Chief Engineer**
Orbiter-based Design Basis Calculations	**NASA - GSFC**	**Project Manager / Chief Engineer**
Phase 3		
Orbital Platform vehicle	**Factory**	**DCMC -FCA/PCA**
Orbital Platform CDR	**Contractor Facility**	**Project Manager**
Orbital Platform Drawings (as designed & as built)	**NASA - GSFC**	**Project Manager / Chief Engineer**
Orbital Platform Design Basis Calculations	**NASA - GSFC**	**Project Manager / Chief Engineer**
All Phases		
Phase Test Plan	**NASA - GSFC**	**Project Manager / Chief Engineer**
Phase Test Results Report	**NASA - GSFC**	**Project Manager / Chief Engineer**
Mission Training	**NASA - GSFC**	**Project Manager / Chief Engineer**
Operations and Maintenance Manuals (ground station, orbiter-based platform, orbital platform)	**NASA - GSFC**	**Project Manager / Chief Engineer**
Cost Accounting Reports	**NASA - GFSC**	**Project Manager**

Figure 3. Data and Hardware Deliverables