National Aeronautics and
Space Administration

SBIR INVESTMENTS

in **ANTENNA TECHNOLOGY**

2005 to 2012

SPACE COMMUNICATIONS AND NAVIGATION

www.nasa.gov

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 antenna technology development for the Space Operations Mission Directorate (SOMD)/Human Exploration and Operations Mission Directorate (HEOMD) from 2005 to 2012. This report summarizes technology challenges addressed and advances made by the SBIR community in antenna 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), 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.

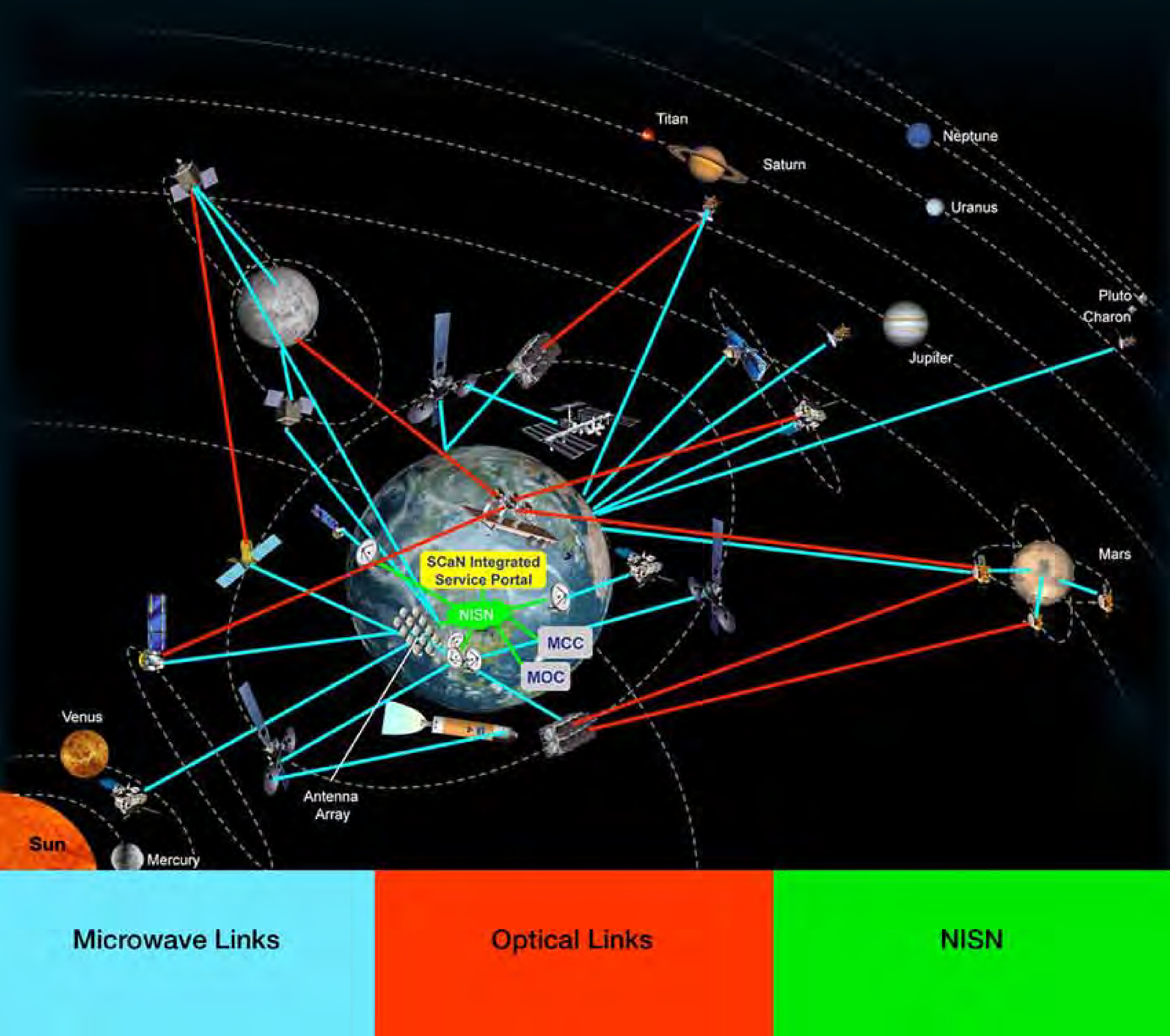
HEOMD mission goals include key technology developments in Space Communications and Navigation, Space Transportation, Human Research and Health Maintenance, Radiation Protection, Life Support and Habitation, High-Efficiency Space Power Systems, and Ground Processing/ISS Utilization.

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 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, 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 SCaN Topic area are aligned with the SCaN Program technical directions.

This document catalogs SCaN SBIR investments in **Antenna Technology** development from 2005 to 2012.

SBIR PHASE I AWARDS

CONTENTS

SBIR PHASE II AWARDS

CONTENTS (CONTINUED)

ANTENNA TECHNOLOGY

NASA seeks advanced antenna systems and technologies to enable communications for future space operations, space science, Earth science, and solar system exploration missions. These areas have been supported by the NASA SBIR Program. The requirements are summarized below.

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

NASA is considering arrays of ground-based antennas to increase capacity and system flexibility, reduce reliance on large antennas and high operating costs, and eliminate single point of failure of large antennas. A large number of smaller antennas arrayed together results in a scalable, evolvable system, which enables a flexible schedule and support for more simultaneous missions. A significant challenge is the implementation of an array for transmitting (uplinking), which may or may not use the same antennas that are used for receiving. Arraying concepts that can enable technology standardization across each NASA network (i.e., Deep Space Network (DSN), Near Earth Network (NEN), and Space Network (SN), within the framework of the newly envisioned NASA integrated network architecture, at Ka-band frequencies and above, are highly desired.

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

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

Typically, the Phase I deliverables are based on research to identify and evaluate candidate telecommunications technology applications to demonstrate the technical feasibility and to show a path towards a hardware/software demonstration. Bench- or lab-level demonstrations are desirable.

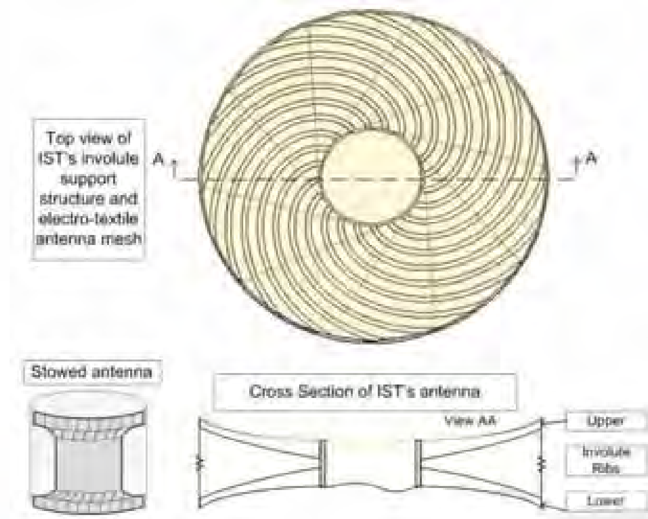
For the Phase II deliverables, emphasis is placed on developing and demonstrating the technology under simulated flight conditions. The effort should outline a path showing how the technology could be developed into spaceworthy systems. The SBIR contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II period of performance.

ANTENNA TECHNOLOGY SBIR PHASE I AWARDS 2005 TO 2012

NOVEL DEPLOYABLE HIGH-FREQUENCY ANTENNAS USING COMPOSITE ELECTROTEXTILES

Infoscitex Corporation

2005 Phase I
01.04-7826



Identification and Significance of Innovation

- NASA and the Air Force need new deployable technologies that can meet the Ka-band communication needs of the next-generation space vehicles
- Infoscitex Corporation's (IST's) new electrotextile composite approach has the potential to significantly reduce the weight of antenna and the necessary backup structure
- Lightweight composite deployable structures with novel involute backing structure can provide a new approach to reaching the antenna areal weight goal of 1 kg/m^2

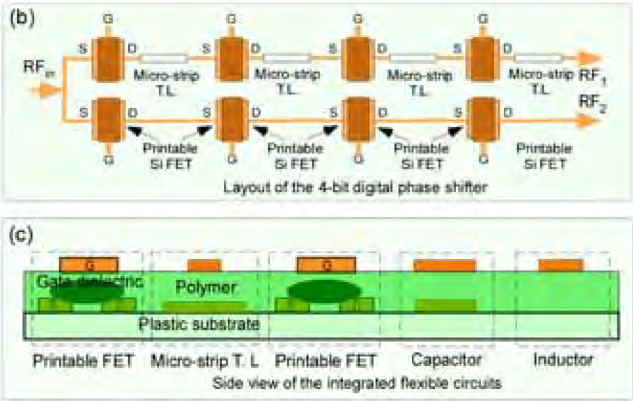
Technical Objectives

- Develop process to produce and weave or knit coated fibers into high-accuracy tight-spacing mesh
- Produce sample mesh prototypes with two or more thermoplastic mesh locking approaches in preparation for passive intermodulation (PIM) testing
- Evaluate the structural, reflectivity, and PIM characteristics of the prototype meshes and downselect best performing mesh for Phase II antenna prototype
- Design involute shape backing structure given the downselected mesh properties and criteria for Ka-band operating frequency (conductor spacing, maximum acceptable surface deviation from ideal parabola, signal gain, etc.)

NASA and Non-NASA Applications

- Ultralightweight, multifunctional durable spacecraft antenna structures
- Flexible lightweight durable antennas for wireless technologies like cellular phones, Global Positioning System (GPS), Bluetooth, and WiFi

A PRINTABLE SILICON NANO-FIELD EFFECT TRANSISTOR WITH HIGH OPERATING FREQUENCY FOR LARGE-AREA DEPLOYABLE ACTIVE PHASED-ARRAY ANTENNAS



Omega Optics, Inc.

2005 Phase I
01.04-7905

Technical Objectives

- Develop and characterize the printable silicon nano-field effect transistor (nano-FET)
- Develop a preliminary digital phase shifter for active phased-array antennas (PAAs)
- Demonstrate the monolithic integration of flexible electronics with large-area and deployable active PAA

NASA Applications

- L-band active PAA
- Smart antenna for adaptive and reliable radiofrequency (RF) communication
- Multiband frequency agile RF radar systems

Non-NASA Applications

- RF identification tags, electronic paper
- Smart cards
- Large-area flat panel displays

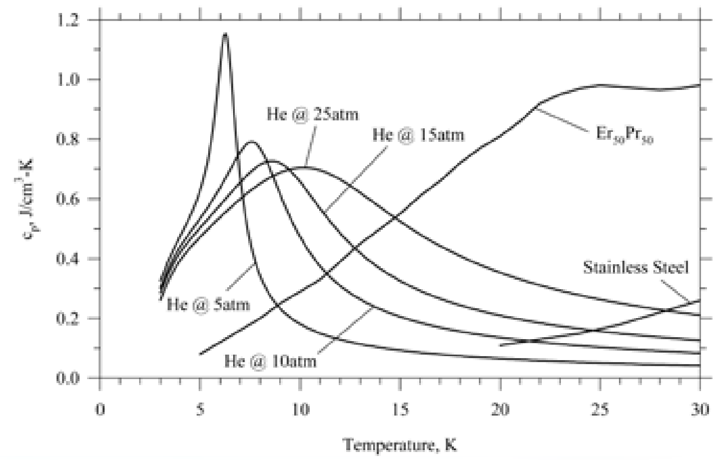
Identification and Significance of Innovation

Flexible electronic circuits are highly desired in NASA's space radar systems due to their easy integration with large-area inflatable antennas. Existing flexible electronics have an intrinsic low switching frequency due to their low carrier mobility. The proposed research aims to develop a printable silicon nano-FET with high carrier mobility of over 400 $cm^2/(V \cdot s)$, which allows us to achieve multi-gigahertz operating frequency. Successfully developing the proposed research is expected to provide an enabling technology for high-speed flexible electronics that can be integrated with large-area, inflatable radar antennas and provide distributed system control, signal processing, and dynamic antenna subarraying, and gain pattern reconfiguration functions.

15- TO 25-K STATIC-HELIUM REGENERATOR/DOUBLE PULSE TUBE COOLER FOR RECEIVING ARRAYS

Beck Engineering, Inc.

2005 Phase I
01.05-9818



Identification and Significance of Innovation

NASA needs a cryogenic refrigerator for the 15 to 25 K range for receiving arrays of ground-based antennas that will serve the telecommunications needs of future space exploration.

We propose to develop a 15 to 25 K Static-Helium Regenerator (SHR)/Double Pulse Tube Cooler (DPTC) that uses two of our technologies to enable efficient operation at cold temperatures:

- SHR can store more heat at cold temperatures than regenerators made from solid materials (e.g., $Er_{50}Pr_{50}$ or stainless steel)
- DPTC technology uses a recuperator, which can operate efficiently at cold temperatures

Technical Objectives

- Project the size, mass, and performance of a 15 to 25 K SHR/DPTC

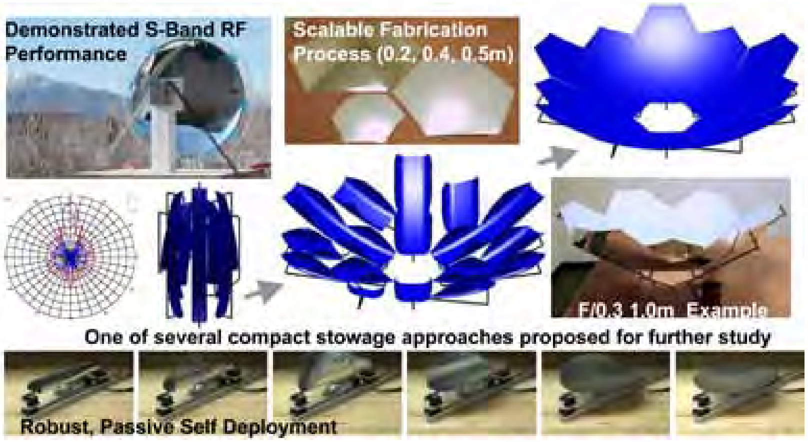
NASA Applications

- Coolers for receiving arrays of ground-based antennas
- Coolers for the Next Generation Telescope (NGST) and the Terrestrial Planet Finder (TPF) missions
- Coolers for the structure and evolution of the universe theme
- Coolers to liquefy and/or store cryogens for human and robotic missions to Mars

Non-NASA Applications

- Air Force coolers for High Energy Laser (HEL) systems
- Air Force coolers for very long wavelength infrared (VLWIR) focal planes

HIGH-GAIN, VERY LOW AREAL DENSITY, SCALABLE SPACE-BASED RADIOFREQUENCY APERTURES ENABLED BY MEMBRANE APERTURE SHELL TECHNOLOGY (MAST)



Mevicon, Inc.

2006 Phase I
01.04-9426

Technical Objectives

- Establish target application, operational scenarios, and system architecture approach
- Demonstrate shell segment fabrication and radiofrequency (RF) performance
- Demonstrate, with hardware, that suitable stowage and deployment scalability paths exist
- Evaluate stowage, launch, and operational environment survival margins
- Develop point design and advance documented technology readiness level (TRL)

NASA and Non-NASA Applications

RF communications

- RF communications relay orbital assets
- Military and commercial space telecom apertures
- High-gain planetary links, point-to-point, long-haul wireless, ground station uplink, and direct to Earth (backup)
- Terrestrial: transportable emergency/remote location very-small-aperture terminal (VSAT) apertures and compact test range subreflectors
- Synergies to Space Science Applications
- Large apertures (RF, mm wave, IR (far, middle, near) science)
- Precision apertures (incoherent coherent LIDAR, spectroscopy, and visible)

Other Exploration/Operational Applications

- Solar concentrators for power (solar dynamic), propulsion (SOTV and STP)
- Sun shields (large RF to deep space IR telescopes), occulters, solar sail. Note: All application areas are dual/multiuse, supporting potential NASA, Department of Defense (DoD), and commercial space applications.

Identification and Significance of Innovation

The proposed innovation is the development/demonstration of methods to scale of Membrane Aperture Shell Technology (MAST) to provide path for 10- to 20-m diameter space-based RF communications apertures. Advantages/significance of the technology include

- Compactly stowable, passively self-deploying, self rigidizing, and good surface figure segments (should support Ka+ bands)
- Ability to fabricate hexagons provides many scalability paths to large outer diameter (OD)
- Based on space-qualified material/coating thin films
- Demonstrated RF reflectivity
- Structural stiffness derived from permanent curvature
- Larger apertures provide increased gain, better communications bandwidth, longer range, and/or reduced power usage
- Lower areal density and thus less mass/inertia loading

SELF-ERECTING COMMUNICATIONS INFRASTRUCTURE

Cornerstone Research Group, Inc.

2006 Phase I
01.04-9591

Identification and Significance of Innovation

- Large-scale, reconfigurable composite structures
- Low-mass and volume packaging
- Self-erecting, payload-lifting composite tower
- Large-area coverage
  - Increases point-to-point range
  - Reduces power requirements
  - Minimizes number of nodes

Technical Objectives

- Identify best reconfigurable beam design
- Demonstrate mechanical beam reconfiguration system
- Develop first-generation tower design

NASA Applications

- Enhanced networked communication performance
- Basic self-erecting infrastructure
- Low-packing volume basic structures for shipping

Non-NASA Applications

- Disaster relief emergency infrastructure
- Affordable laborless cellular telephone towers
- Self-erecting bridges

LIGHTWEIGHT SELF-CORRECTING INFLATABLE/RIGIDIZABLE SPACE ANTENNAS

14-m-diam. inflatable antenna experiment

Inflatably deployed rigidizable antenna reflector

L'Garde, Inc.

2006 Phase I
01.04-9843

Technical Objectives

- Carry out concept design of accurate, long-lived lightweight inflatable-rigidizable space antenna
- Calculate resulting shapes of "distorted" antenna reflector surface due to manufacturing and on-orbit error sources
- Identify, assess, and quantity feasibility of applying specific candidate distortion-compensation mechanisms/algorithms to inflatable-rigidizable antennas to increase operating frequency
- Use the"distorted" antenna reflector shapes and apply the compensation system to predict antenna performance
- Plan Phase II radiofrequency (RF) test and validation on a subscale inflatable-rigidizable antenna reflector

NASA Applications

- NASA space science missions and communications from outer planets to NASA terrestrial facilities and/or Earth orbits

Non-NASA Applications

- High data throughput applications when ease and cost of transporting large apertures is of prime importance such as during natural or manmade disasters in a combat theater

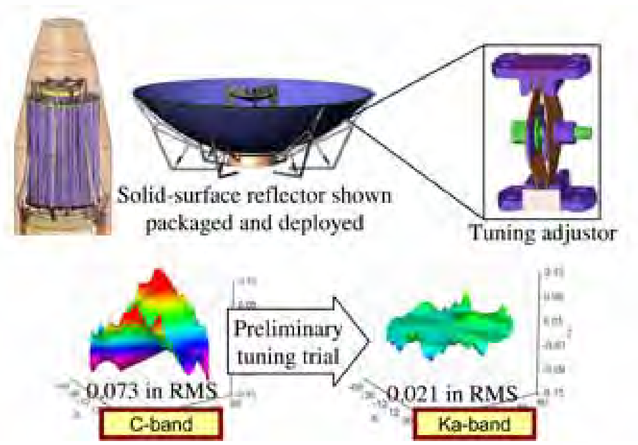
Identification and Significance of Innovation

- Inflatable-rigidizable large apertures in space offer low-weight and low-cost alternatives to rigid mechanical deployables—no makeup gas necessary
- Antenna surface distortions on-orbit to be compensated for by a real-time RF distortion-compensation using phased-array feed system
- 20-m-class aperture diameter or greater easily achievable with technology

SURFACE OPTIMIZATION TECHNIQUES FOR DEPLOYABLE REFLECTORS

Composite Technology Development, Inc.

2007 Phase I
01.04-8808



Identification and Significance of Innovation

- Develop methods for optimizing the surface contour of solid-surface deployable reflectors
- Development of built-in tuning adjustors
- Enables deployable reflectors that are capable of both high-gain (due to large aperture) and high-frequency (due to precision solid-surface) operation
- Composite solid-surface reflector low-cost and near-zero coefficient of thermal expansion (CTE)

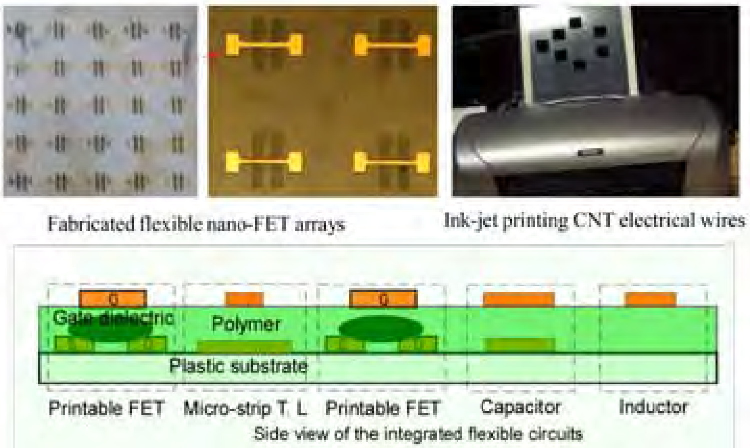
Technical Objectives

- Identify baseline reflector application and define tuning requirements
- Design engineering unit with tuning adjustors and validate tuning influence with structural analysis
- Fabricate engineering unit with existing solid surface deployable reflector shell
- Demonstrate surface optimization using tuning adjustors

NASA and Non-NASA Applications

- Next Generation DSN/TDRS
- Harris Corp.: 20M Mars Comm System
- Boeing: Lunar TDRS/DSN
- Radar/radiofrequency (RF) payload for Department of Defense (DoD) TacSats
- Commercial communication payloads

PRINTABLE NANO-FIELD EFFECT TRANSISTORS COMBINED WITH CARBON-NANOTUBE-BASED PRINTABLE INTERCONNECT WIRES FOR LARGE-AREA DEPLOYABLE ACTIVE PHASED-ARRAY ANTENNAS



Fabricated flexible nano-FET arrays

Ink-jet printing CNT electrical wires

Side view of the integrated flexible circuits

Omega Optics, Inc.

2007 Phase I
01.04-8886

Technical Objectives

- Develop and characterize the printable silicon nano-field effect transistor (nano-FET)
- Develop and characterize the printable carbon nanotube interconnect wires
- Demonstrate the integrated printable nano-FET network for active phased-array antenna

NASA Applications

- Active, multiband phased-array radar systems
- Advanced navigation and communication, including basic mission support and high bandwidth demand, to implement the vision of going back to Moon by 2020

Non-NASA Applications

- Radiofrequency (RF) identification tags and electronic paper
- Smart cards
- Large-area flat panel displays

Identification and Significance of Innovation

Flexible electronic circuits are highly desired in NASA's space radar systems due to their easy integration with large area inflatable antennas. Existing flexible electronics have an intrinsic low switching frequency due to their low carrier mobility. The proposed research aims to develop a printable silicon nano-FET with high carrier mobility of over 400 $cm^2/(V \cdot s)$, which allows us to achieve multi-gigahertz operating frequency. We also propose the printing of conducting interconnect wires using carbon nanotubes. Based on our past experience on printable silicon nano-FET and printable carbon nanotube wires, the high-speed flexible electronics are expected to be integrated with large-area, inflatable radar antennas and achieve smart antenna systems for high performance and reliable space operations.

FOAMED ANTENNA SUPPORT FOR VERY LARGE APERTURES

Adherent Technologies, Inc.

2007 Phase I
01.04-9130

Lightweight antenna concepts

Identification and Significance of Innovation

- Very large aperture antennas require low areal weight support
- Wire mesh too heavy and membrane with inflated support not damage tolerant and subject to shape fluctuations
- New support structure needed

Solution: rigidized inflatable with foam core for stability and damage tolerance

Technical Objectives

- Develop rigidized inflatable as mold for core
- Demonstrate foam can be used to fill mold for antenna stabilization

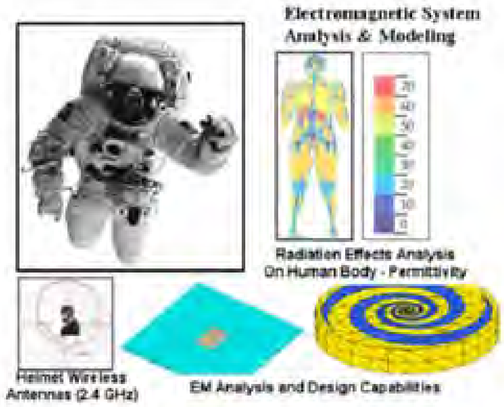
NASA Applications

- Large aperture antennas for deep space communication

Non-NASA Applications

- All commercial and military communication satellites

CONFORMAL SPACESUIT ANTENNA DEVELOPMENT FOR ENHANCED EXTRAVEHICULAR ACTIVITY COMMUNICATIONS AND WEARABLE COMPUTER APPLICATIONS



Conformal spacesuit antenna for enhanced EVA communications

Applied EM, Inc.

2007 Phase I
01.04-9232

Technical Objectives

- Design and develop conformal spacesuit (body-worn) antennas for enhanced communications during extravehicular activity (EVA)
- Develop fabrication methods for body-worn antennas that use conductive textile, polymer coatings, and wiring methods
- Develop methods to integrate body-worn antennas into the 11 plies of the current spacesuit designs
- Provide electromagnetic (EM) simulations and performance of antenna designs

NASA Applications

- Conformal astronaut (body-worn) antennas for spacesuit EVA operations
- Antennas for wireless access points for wearable computer designs for astronauts
- New spacesuit designs using novel integrated antenna systems

Non-NASA Applications

- Body-worn antennas for Warfighter Department of Defense (DoD) applications
- Commercial applications using body-worn antennas for new suit and uniform designs requiring communications

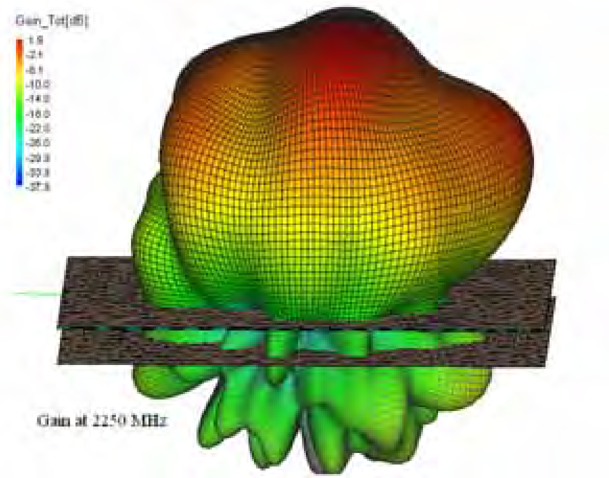
Identification and Significance of Innovation

As NASA prepares for future space missions and return to the Moon by 2020, astronauts will be required to spend more time exposed to the hazards of EVA. Providing reliable communications during EVA operations is imperative not only to relay progress but also to monitor the health and ability of the astronaut. In order to improve space-to-space communications, Applied EM, Inc., is developing conformal, body-worn antennas that will be integrated into spacesuit designs to enhance EVA operations. Included in these developments are wireless antennas for wearable computers.

PHASE-ARRAY ANTENNA WITH ADAPTIVE DIGITAL SIGNAL PROCESSOR BEAMFORMING

Nokomis, Inc.

2008 Phase I
01.02-8858



Broadband microstrip coupled slot simulated results

Identification and Significance of Innovation

- Digital signal processor (DSP) beamforming for commercial cellular applications has improved signal-to-noise ratio by pointing the main beam toward the signal of interest. To extend this advantage to wideband communication systems, conformal adaptive beamforming antennas are needed.
- The need for an adaptive antenna array in space for varying temperature and vibration can also be met with DSP control.
- Efficiency and sensitivity are improved by integration of electronics and the simplification of antenna feed system leading to more focus on conformal antenna array optimization.
- An adaptive array is necessary for beamforming over an extended frequency band.

Technical Objectives

- High gain and low relative side lobe level for a small array
- Up to 500 MHz bandwidth for an S-band array for communications and data systems
- Self calibrating for phase drift due to cable movement and temperature shift
- Wide field of view to accommodate mobility of small space vehicles

NASA Applications

- Radiofrequency (RF) communications
- Architectures and networks
- Guidance, navigation, and control
- Telemetry, tracking, and control
- Airport infrastructure and safety

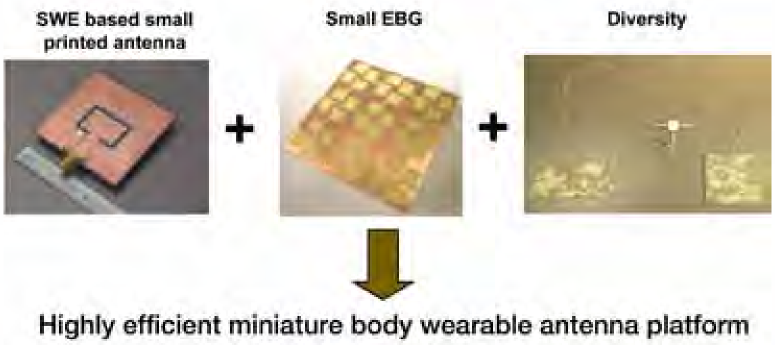
Non-NASA Applications

- Cellular base stations
- Airliner cellular base stations
- WiFi remote access
- Satellite telephones

EFFICIENT WEARABLE ANTENNAS FOR ASTRONAUT EXTRAVEHICULAR ACTIVITY COMMUNICATIONS

Pharad, LLC

2008 Phase I
01.02-9948



Technical Objectives

- The overall objective is to create an unobtrusive body-wearable antenna platform for astronaut radiofrequency (RF) communications.
- Throughout this project, proof-of-concept versions of the new concepts will be developed and tested.

NASA and Non-NASA Applications

- Improved performance of space RF communication systems operating in the ultrahigh frequency (UHF) band as well as other higher frequencies
- Astronaut Extravehicular Mobility Unit (EMU) suits with directly integrated small, highly efficient body-wearable radiators
- Body-worn antennas for U.S. Army soldiers
- Hands-free, unobtrusive communication systems for first responders, fire fighters, and emergency personnel
- Multifunction body-wearable radiators for commercial wireless communications (UHF, Global Positioning System (GPS), WLAN)

Identification and Significance of Innovation

- We are creating a new class of small, highly efficient body-wearable antenna platforms that can be integrated directly into astronaut EMU suits for RF communications.
- Our technique combines new small uniplanar antennas based on slow wave engineering (SWE) techniques and electrically small electromagnetic bandgap (EBG) structures with diversity schemes to yield compact, efficient radiating solutions.
- The innovation will provide an unobtrusive high-performance radiating platform that will greatly improve astronaut EVA communications.

STRESS-MATCHED RADIOFREQUENCY AND THERMAL CONTROL COATINGS FOR MEMBRANE ANTENNAS

Surface Optics Corporation

2009 Phase I
01.02-8188

Thermally stable, large RF space aperture

Identification and Significance of Innovation

Polymer membrane technologies offer the greatest promise of meeting future large antenna requirements, while significantly reducing system mass and launch volume. Recent advances in polymer film materials must be matched by advances in the coatings that provide the RF and thermal performance in a space environment. Surface Optics Corporation (SOC) will develop a coating process that results in a membrane/coating material with zero coefficient of thermal expansion (CTE). Results in thermally stable membrane antennae.

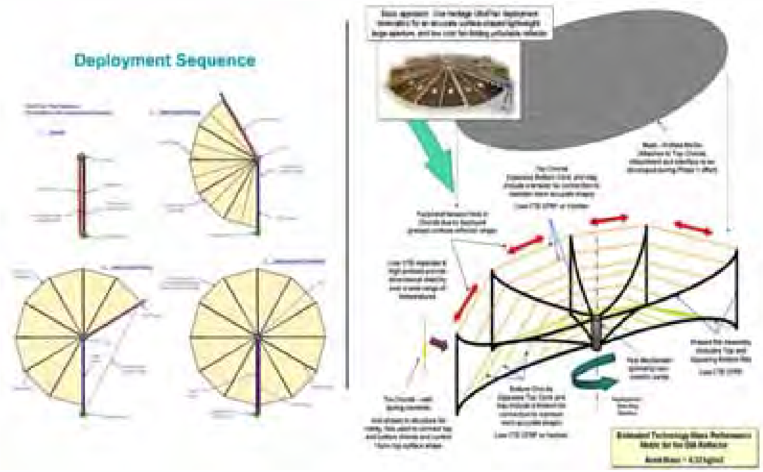
Technical Objectives

- Employ stress tuning deposition techniques to deposit Al/SiO_2 coatings
- Tailor coating/membrane properties to achieve zero CTE

NASA and Non-NASA Applications

- Commercial, NASA, and Department of Defense (DoD) RF communication antennae
- NASA instruments for Earth and space science

AFFORDABLE UNFURLABLE FAN-FOLD WRAPABLE REFLECTOR FOR SMALL AND LARGE APERTURES



Deployable Space Systems, Inc.

2009 Phase I
01.02-8308

Technical Objectives

- Establish concept feasibility of an optimized fan-fold-wrap reflector technology and demonstrate technology readiness level (TRL) 3/4
- Establish concept feasibility and TRL 3/4 through requirements definition, detailed design and development efforts, analytical modeling activities (including structural, thermal, mass properties, and surface accuracy), and proof-of-concept hardware

NASA and Non-NASA Applications

- Technology infusion identified for many NASA and non-NASA missions
- Applicable opportunities: geostationary orbit (GEO), low Earth orbit (LEO), and medium Earth orbit (MEO), interplanetary, and lunar/planetary surface lander communications missions
- Technology viable to all Department of Defense (DoD), NASA, civilian, and prime contractor end users as a direct replacement for current state-of-the-art reflector technologies used in marketplace
- Nonspace applications include fixed, mobile, and deployable ground-based communications or optical reflectors to support renewable energy photovoltaic concentrator systems

Identification and Significance of Innovation

Mission-enabling compared to current state of the art

- Ultralightweight (projected <0.32 kg/rn^2 areal mass)
- Compact stowage volume (>53:1 compaction ratio)
- High-heritage/reliable deployment mechanization
- Functional deployment capability in 1 g
- Low thermal distortion
- High stiffness
- Expandable to large apertures (3 m to 50 m+ diameter)
- Affordable
- RF performance over wide frequency (L, X, Ku, and Ka)

A MULTIBAND PHOTONIC PHASED-ARRAY ANTENNA FOR HIGH-DATA-RATE COMMUNICATION

Crystal Research, Inc.

2009 Phase I
01.02-9839

Identification and Significance of Innovation

Crystal Research, Inc., proposes to develop a multiband photonic-antenna-based on a high-speed optical true-time-delay beamformer, capable of simultaneously steering multiple independent radiofrequency (RF) beams in less than 300 ns. Such a high steering speed is 3 orders of magnitude faster than any other existing optical beamformers. Unlike other approaches, the proposed technology uses a single controlling device per operation band, which eliminates the need for massive optical switches, laser diodes, and fiber Bragg gratings.

Technical Objectives

The objective of the proposed Phase I work is to demonstrate the feasibility and advantages of a multi-band photonic phased array antenna using an innovative high-speed electro-optic beamformer.

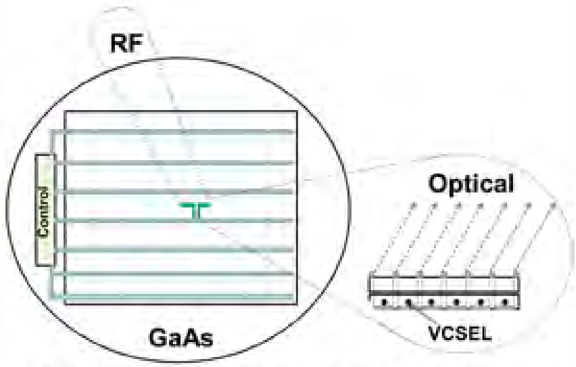
NASA and Non-NASA Applications

The multi-band photonic phased array antenna can be used for NASA (1) high-data rate communication and (2) remote sensing applications. Potential communications applications include lunar and planetary exploration and Lunar Relay Satellites. Potential remote sensing applications include: synthetic aperture radar (SAR) platforms for planetary science. It is also an important step towards continued commercialization of low cost phased array antennas for mobile satellite communications applications.

OPTOELECTRONIC INFRASTRUCTURE FOR RADIOFREQUENCY/OPTICAL PHASED ARRAYS

ODIS, Inc.

2010 Phase I
01.01-9727



RF-optical shared aperture phased array

Technical Objectives

- Demonstrate feasibility of combining radiofrequency (RF) and optical emission from a single aperture
- Demonstrate feasibility of optical control of RF power and beam direction
- Demonstrate two-dimensional optical beam emission and phase modulators for beam steering

NASA Applications

- Satellite sensors in the Ka- and Ku-band for surface object characterization
- POET circuits for laser and RF communications, internal satellite networking, RF photonics and AD conversion, and high-speed systems
- POET imaging devices for longwave infrared (LWIR) THz

Non-NASA Applications

- Data comm, FTTH, LANS, active optical cables, and high-speed servers
- Digital signal processors (DSPs) and FPAs

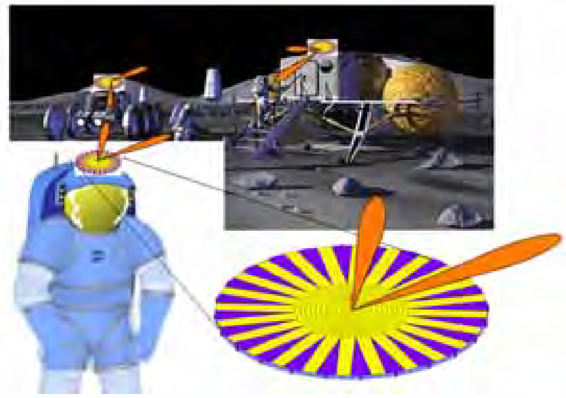
Identification and Significance of Innovation

- Optoelectronic integration enables co-location of RF and optically emitting devices
- Compact Vertical Cavity Surface Emitting Laser (VCSEL) structure enables coherent beams and phase modulators enable beam steering
- Optical distribution of RF and optical beam control
- Integrated true time delay for RF beam control

ELECTRONICALLY STEERABLE ANTENNAS WITH PANORAMIC SCAN FIELD OF VIEW

Freeform Wave Technologies, LLC

2010 Phase I
01.01-9815



Identification and Significance of Innovation

Electronically steerable antennas (ESAs) are key to effective radio transmission at millimeter-wave frequencies. To enable communication with rovers, robots, extravehicular activity (EVA) astronauts, and other mobile surface assets in planetary explorations, ESAs must be capable of 360-degree azimuth scan, and in some cases, multiple independently steerable beams. The proposed research aims to develop a passive ESA technology with these capabilities to address NASA's communication and navigation needs at K and Ka frequency bands. Compared to phased arrays, the proposed approach leads to dramatically smaller and lighter ESA solutions that are ideal for low-power mobile and deployable radio platforms.

Technical Objectives

- Design, characterize, and optimize miniature passive beamforming networks based on metamaterial techniques
- Investigate switch technologies
- Investigate generalizations of the proposed method for two-dimensional beam steering

NASA Applications

- Rovers, robots, mobile habitats, and science instruments
- Lunar communication terminal(s) and base stations
- EVA suit (helmet)
- Radar navigation for highly maneuverable platforms

Non-NASA Applications

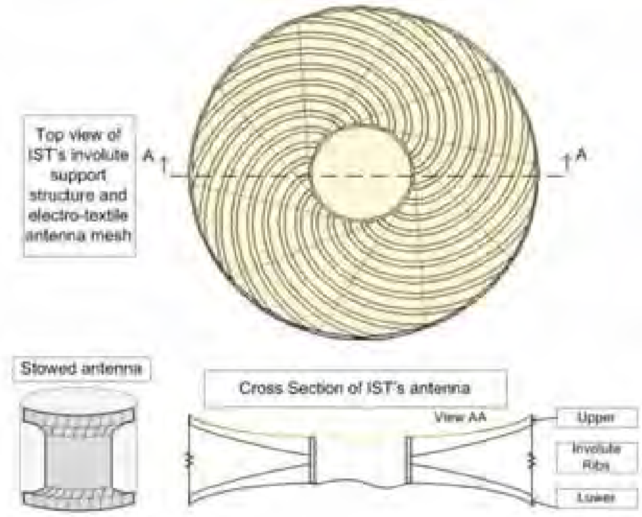
- Helicopter landing aid Department of Defense (DoD)
- Automotive radars
- 60-GHz communication radios

ANTENNA TECHNOLOGY SBIR PHASE II AWARDS 2005 TO 2012

NOVEL DEPLOYABLE HIGH-FREQUENCY ANTENNAS USING COMPOSITE ELECTROTEXTILES

Infoscitex Corporation

2005 Phase II
01.04-7826



Identification and Significance of Innovation

- NASA and the Air Force need new deployable technologies that can meet the Ka-band communication needs of the next-generation space vehicles
- Infoscitex Corporation's (IST's) new electrotextile composite approach has the potential to significantly reduce the weight of antenna and the necessary backup structure
- Lightweight composite deployable structures with novel involute backing structure can provide a new approach to reaching the antenna areal weight goal of 1 kg/m^2

Technical Objectives

- Develop process to produce and weave or knit coated fibers into high-accuracy tight-spacing mesh
- Produce sample mesh prototypes with two or more thermoplastic mesh locking approaches in preparation for passive intermodulation (PIM) testing
- Evaluate the structural, reflectivity, and PIM characteristics of the prototype meshes and downselect best performing mesh for Phase II antenna prototype
- Design involute shape backing structure given the downselected mesh properties and criteria for Ka-band operating frequency (conductor spacing, maximum acceptable surface deviation from ideal parabola, signal gain, etc.)

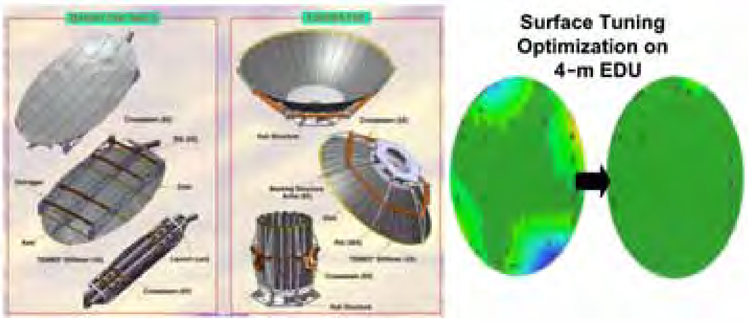
NASA and Non-NASA Applications

- Ultralightweight, multifunctional durable spacecraft antenna structures
- Flexible lightweight durable antennas for wireless technologies such as cellular phones, Global Positioning System (GPS), Bluetooth, and WiFi

SURFACE OPTIMIZATION TECHNIQUES FOR DEPLOYABLE REFLECTORS

Composite Technology Development, Inc.

2007 Phase II
01.04-8808



Technical Objectives

- Assembled 4-m-offset-shaped engineering design unit (EDU) with
  – Deployable backing structure
  – Surface tuning hardware
- Packaging and gravity off-loading and tuning hardware validation
- System-level testing to be performed in June/July
  – RF testing to Ka-band
  – Stowage/deployment

Proposed Phase-2E Effort: Technology Readiness Levels (TRLs) 4 to 5

- System-level design for Advanced Colloids Experiment (ACE) mission (NASA/Jet Propulsion Laboratory)
- Upgrade EDU to flight-representative (i.e., thermally stable) materials
- Validate that surface optimization is maintained through system-level thermal distortion testing

Identification and Significance of Innovation

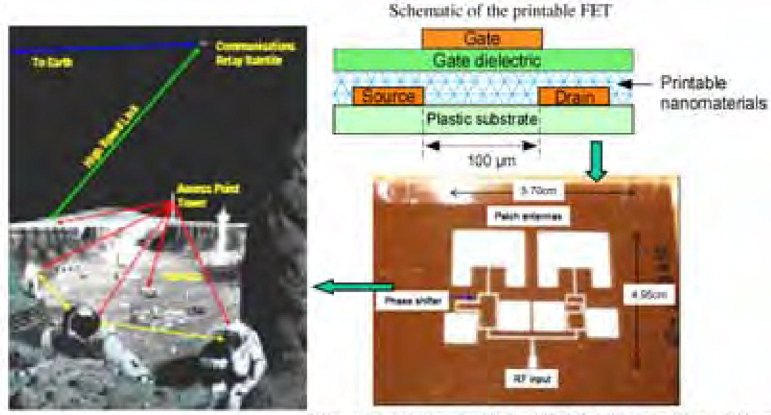
Shape memory composites enable next-generation deployable antenna technologies

- 4- to 6-m solid surface deployable reflectors
- Tunable to high-frequency deployable communications and RADAR (> Ka band)
- Low-cost, low-risk, 9-month delivery

FULLY PRINTED FLEXIBLE 4-BIT TWO-DIMENSIONAL (4X4) 16-ELEMENT PHASED-ARRAY ANTENNA FOR LUNAR SURFACE COMMUNICATIONS

Omega Optics, Inc.

2007 Phase II
01.04-8886



Fully printed 2-element PAA with 2-bit FET based phase shifters

Identification and Significance of Innovation

NASA's future exploration missions focus on the manned exploration of the Moon, Mars, and beyond, which will rely heavily on the development of a reliable communications infrastructure from planetary surface-to-surface, surface-to-orbit, and back to Earth. Flexible antennas are highly desired in many scenarios. Existing flexible electronics have an intrinsic low switching frequency due to their low carrier mobility. The carbon nanotube (CNT) network in solution we used has carrier mobility as high as 46,770 $cm^2/(V \cdot s)$, and a large current-density carrying capacity of ~1000 mA/cm^2, corresponding to a high carrying power of over 2000 mW/cm^2. Such high carrier mobility and large current carrying capacity allow us to achieve high-speed (>100 GHz), high-power flexible electronic circuits and antennas. A prototype of a fully printed 4-bit two-dimensional 16-element phased-array antenna on flexible substrate such as Kapton, including field-effect-transistor- (FET-) based T/R module and phase shifters will be developed. The printing technology and high-speed electronics will enable active phased-array antenna (PAA) deployment for NASA's lunar mission, including pressurized rovers, pressurized habitats, surface navigation, extravehicular activities (EVA), etc.

Technical Objectives

- Develop fully printable 4-bit two-dimensional (4x4) 16-element PAAs at S-band for lunar communications
- Develop the fully printable integrated circuit technology and multi-layer printing and interconnection technology on flexible substrates
- Develop the T/R module including phase shifters and amplifiers
- Develop a prototype of the fully printed PAA, and perform reliability tests

NASA Applications

- Lunar local communication networks at ultrahigh frequency (UHF)/L/S/C bands
- "Stick-on" spacesuit for human EVA
- Large inflatable PAA
- High-power electronics/antenna

Non-NASA Applications

- RF identification tags, sensors
- Smart cards, electronic paper
- Large-area flat panel displays

FOAMED ANTENNA SUPPORT FOR VERY LARGE APERTURES

Adherent Technologies, Inc.

2007 Phase II
01.04-9130


Inflated antenna mold


Foam stabilized antenna

Technical Objectives

To optimize the foam technology developed in Phase I to produce a functional 3-m antenna for the Ka band. Towards this goal, Adherent Technologies, Inc., will team with ILC Dover and Applied EM.

NASA Applications

- Very large aperture antennas for interplanetary relays

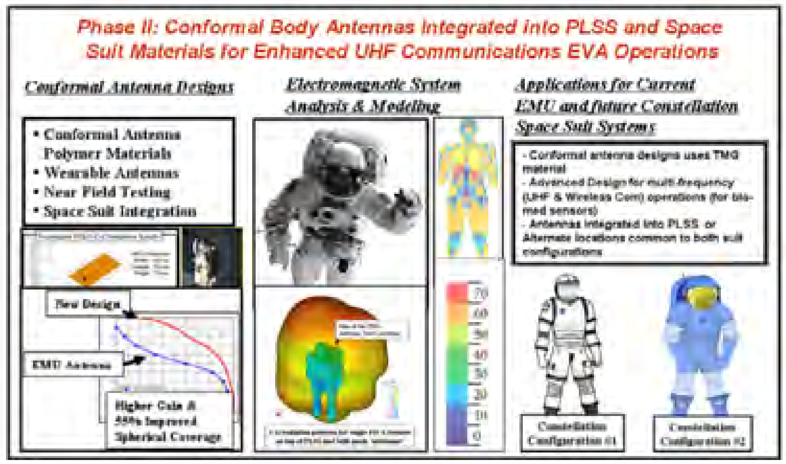
Non-NASA Applications

- Very lightweight shelters for semipermanent installation in both emergency management and military applications

Identification and Significance of Innovation

- Foaming in vacuum technology
- Enables in-space production of lightweight foams to stabilize inflatable structures
- Makes 1-kg/m^3 areal density large aperture antennas possible

CONFORMAL SPACESUIT ANTENNA DEVELOPMENT FOR ENHANCED EXTRAVEHICULAR ACTIVITY COMMUNICATIONS AND WEARABLE COMPUTER APPLICATIONS



Applied EM, Inc.

2007 Phase II
01.04-9232

Identification and Significance of Innovation

As NASA prepares for future space missions and to return to the Moon by 2020, astronauts will be required to spend more time exposed to the hazards of extravehicular activity (EVA). Providing reliable communications during EVA operations is imperative not only to relay progress but also to monitor the health and ability of the astronaut. In order to improve space-to-space communications, Applied EM, Inc., will apply Phase I conformal, body-worn antenna designs, which were evaluated during near-field tests to demonstrate applicability for current Extravehicular Mobility Unit (EMU) and future Constellation spacesuit systems. Included in these developments are wireless antennas for wearable computers.

Technical Objectives

- Apply Phase I conformal spacesuit (body-worn) antenna designs for enhanced communications during EVA
- Develop fabrication methods for conformal spacesuit antennas using advanced polymer dielectric and conductive coatings and wiring methods
- Develop methods to integrate conformal body-worn antennas into current EMU spacesuits and possible future Constellation spacesuit mission applications
- Provide EM performance simulations of antenna designs

NASA Applications

- Conformal astronaut (body-worn) antennas for spacesuit EVA operations
- Antennas for wireless access points for wearable computer designs for astronauts
- New spacesuit designs using novel integrated antenna systems

Non-NASA Applications

- Body-worn antennas for Warfighter Department of Defense (DoD) applications
- Commercial applications using body-worn antennas for protective clothing such as chem-bio, fire retardant, ballistic protection, and athletic clothing

STRESS-MATCHED RADIOFREQUENCY AND THERMAL CONTROL COATINGS FOR MEMBRANE ANTENNAS

Surface Optics Corporation

2009 Phase II
01.02-8188

Technical Objectives

- Develop coating that closely matches stress with coefficient of thermal expansion (CTE) of selected polymer; good adhesion; and thermally stable in space

NASA and Non-NASA Applications

- NASA radiofrequency (RF) communication antennas for space applications
- Department of Defense (DoD) programs using large area polymeric antennas

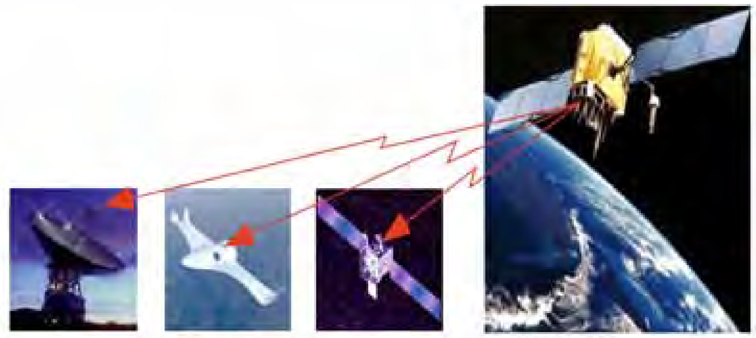
Identification and Significance of Innovation

Development of multimeter diameter RF antennas is a current area of research for NASA and DoD. In Phase I Surface Optics Corporation investigated, in coordination with NeXolve, Al coatings (using stencil-type masking) on a variety of low CTE polymeric materials for evaluation for electrical deflection, low stress, low solar absorption, and high emissivity. The new coatings exhibited significant positive results in the preliminary testing.

A MULTIBAND PHOTONIC PHASED-ARRAY ANTENNA FOR HIGH-DATA-RATE COMMUNICATION

Crystal Research, Inc.

2009 Phase II
01.02-9839



Multiband communications using photonic phased-array antennas

Identification and Significance of Innovation

Crystal Research, Inc., proposes to develop a multiband photonic antenna based on a high-speed optical true-time-delay beamformer, capable of simultaneously steering multiple independent radiofrequency (RF) beams in less than 1000 ns. Such a high steering speed is 3 orders of magnitude faster than any other existing optical beamformers. Unlike other approaches, the proposed technology uses a single controlling device per operation band, which eliminates the need for massive optical switches, laser diodes, and fiber Bragg gratings.

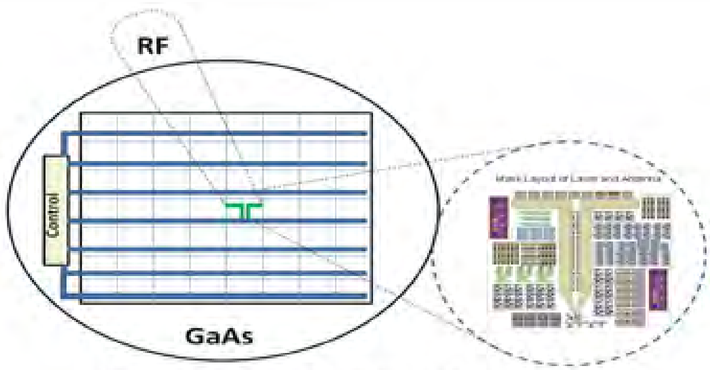
Technical Objectives

The primary objective is to fabricate a multiband photonic phased-array antenna, which can be transitioned into NASA applications.

NASA and Non-NASA Applications

The multiband photonic phased-array antenna can be used for NASA (1) high-data rate communication and (2) remote sensing applications. Potential communications applications include lunar and planetary exploration and lunar relay satellites. Potential remote sensing applications include synthetic aperture radar (SAR) platforms for planetary science. It is also an important step towards continued commercialization of low-cost phased-array antennas for mobile satellite communications applications.

OPTOELECTRONIC INFRASTRUCTURE FOR RADIOFREQUENCY/OPTICAL PHASED ARRAYS



RF-optical shared aperture phased array

ODIS, Inc.

2010 Phase II
01.01-9727

Technical Objectives

- Demonstrate feasibility of combining radiofrequency (RF) and optical emission from a single aperture
- Demonstrate generation of low phase noise RF using an optoelectronic oscillator
- Demonstrate true time delay RF array steering using micro-resonators to produce differential group delay
- Demonstrate feasibility of optical distribution of RF power and optoelectronic control of beam direction
- Demonstrate two-dimensional optical beam steering from coherent array by current control
- Prove viability of optoelectronic architecture for RF/optical cell

NASA Applications

- Satellite sensors in the Ka- and Ku-band for surface object characterization
- POET circuits for laser and RF communications, internal satellite networking, RF photonics and AD conversion, and high-speed systems
- POET imaging devices for longwave infrared (LWIR) THz

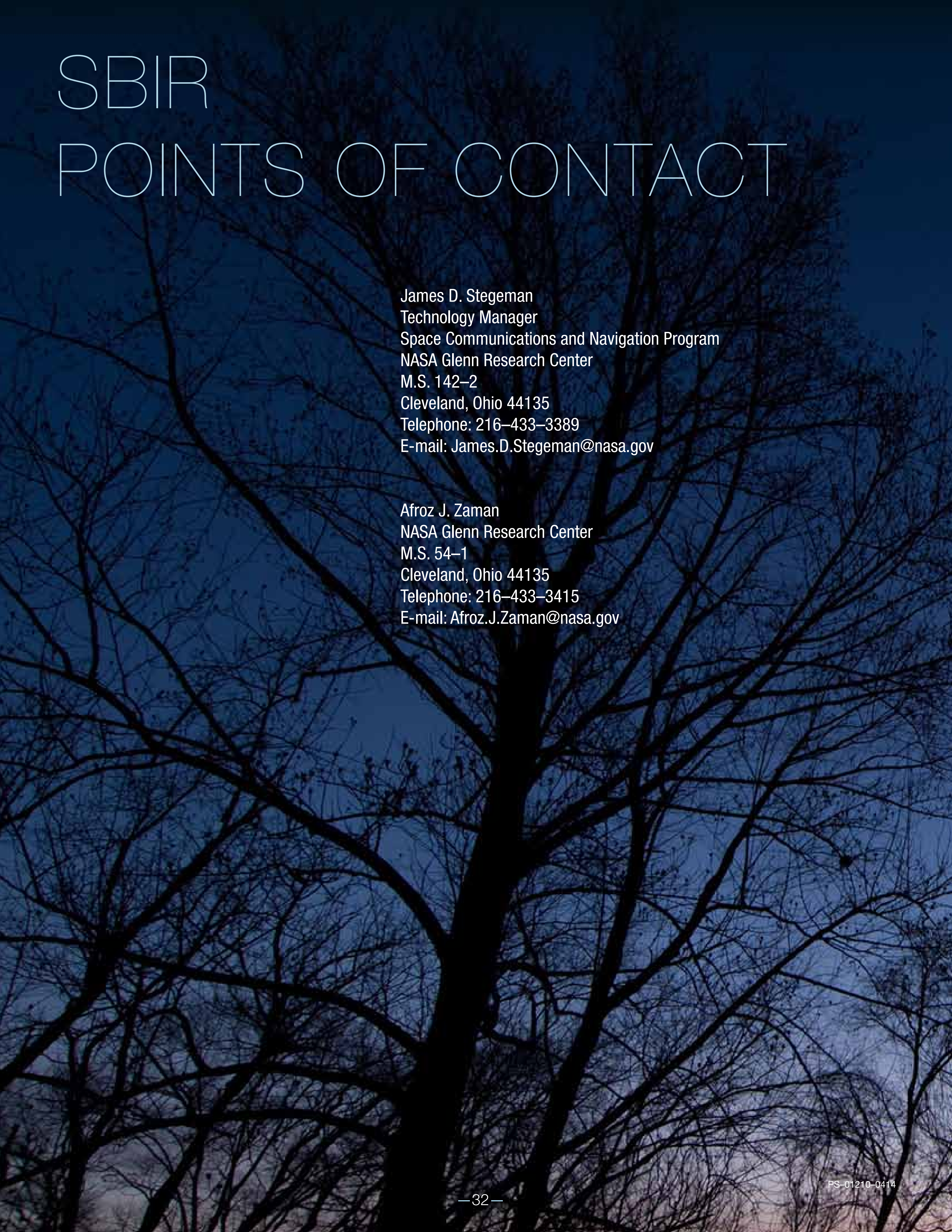
Non-NASA Applications

- Data comm, FTTH, LANS, active optical cables, and high-speed servers
- Digital signal processors (DSPs) and FPAs

Identification and Significance of Innovation

- Optoelectronic integration enables co-location of RF and optically emitting devices in array formats
- Planar Vertical Cavity Surface Emitting Laser (VCSEL) structure enables antiguiding to produce coherent optical beams
- Beam steering of supermodes by current control in X-Y array
- Optical distribution of RF by photodetector conversion
- RF generation by optoelectronic oscillator in a PLL with RF photonic filtering of required harmonic
- Optical remoting of return signal
- True time delay by differential group delay for RF beam steering
- POET is a broad integration platform for multiple NASA applications

COMPANY NAMES



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