NASA’s plans for the manned exploration of the Moon and Mars will rely heavily on the development of a reliable communications infrastructure from planetary surface-to-surface, surface-to-orbit and back to Earth. Future missions will thus focus not only on gathering scientific data, but also on the formation of the communications network. In either case, unique requirements become imposed on the antenna technologies necessary to accomplish these tasks. For example, proximity (i.e., short distance) surface activity applications such as robotic rovers, human extravehicular activities (EVA), and probes will require small size, lightweight, low power, multi-functionality, and robustness for the antenna elements being considered. In contrast, trunk-line communications to a centralized habitat on the surface and back to Earth (e.g., relays, satellites, and landers) will necessitate high gain, low mass antennas such as novel inflatable/deployable antennas. Likewise, the plethora of low to high data rate services desired to guarantee the safety and quality of mission data for robotic and human exploration will place additional demands on the technology.

Over the last few years, NASA Glenn Research Center has been heavily involved in the development and evaluation of candidate antenna technologies with the potential for meeting the aforementioned requirements. These technologies range from electrically small antennas to phased arrays and large inflatable antenna structures. A summary of these efforts will be discussed in this paper. NASA planned activities under the Exploration Vision as they pertain to the communications architecture for the Lunar and Martian scenarios will be discussed, with emphasis on the desirable qualities of potential antenna element designs for envisioned communications assets. Identified frequency allocations for the Lunar and Martian surfaces, as well as asset-specific data services will be described to develop a foundation for viable antenna technologies which might address these requirements and help guide future technology development decisions.
A Review of Antenna Technologies for Future NASA Exploration Missions

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Tel: 216-433-6589

12th Ka and Broadband Communications Conference
Naples, Italy
September 27-29, 2006
Outline of Presentation

• The Vision for Space Exploration
• Communications Architecture for Exploration
• Asset-Specific Communications Requirements
• Summary of Relevant Antenna Technologies
• Conclusions
A Bold Vision for Space Exploration

- Complete the International Space Station
- Safely fly the Space Shuttle until 2010
- Develop and fly the Crew Exploration Vehicle no later than 2014 (goal of 2012)
- Return to the Moon no later than 2020
- Extend human presence across the solar system and beyond
- Implement a sustained and affordable human and robotic program
- Develop supporting innovative technologies, knowledge, and infrastructures
- Promote international and commercial participation in exploration
Communications Network Architecture

Top Level Conceptual Communication Architecture ~2030: A “network of networks”

- Martian Local Network
- Lunar Local Network
- Martian Trunk
- Lunar Trunk
- L1/L2 Individual Spacecraft Connections
- Earth Local Network

Communications architecture on the Lunar Surface


### Characteristics of Communication Assets for the Lunar and Martian Networks

<table>
<thead>
<tr>
<th>Communications Asset</th>
<th>Frequencies</th>
<th>Data Rates</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The Moon</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lunar Reconnaissance Orbiter</td>
<td>S-band</td>
<td>125 to 256 bps</td>
<td>TT&amp;C/Rx from Earth</td>
</tr>
<tr>
<td></td>
<td>UHF/S-band</td>
<td>125 to 256 bps</td>
<td>Tx/Rx to Moon</td>
</tr>
<tr>
<td></td>
<td>Ka-band</td>
<td>&gt; 100 Mbps</td>
<td>Tx to Earth</td>
</tr>
<tr>
<td>Robotic Lunar Exploration Landers</td>
<td>S-band/Ka-band</td>
<td>TBD</td>
<td>Tx/Rx to Earth</td>
</tr>
<tr>
<td></td>
<td>UHF</td>
<td>TBD</td>
<td>Surface Comm.</td>
</tr>
<tr>
<td><strong>Mars</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mars Reconnaissance Orbiter</td>
<td>X-band</td>
<td>300 kbps</td>
<td>Tx/Rx to Earth</td>
</tr>
<tr>
<td></td>
<td>UHF</td>
<td>0.1 to 1 Mbps</td>
<td>Tx/Rx to Mars</td>
</tr>
<tr>
<td></td>
<td>Ka-band</td>
<td>5 Mbps</td>
<td>Tx to Earth</td>
</tr>
<tr>
<td>Mars Global Surveyor</td>
<td>X-band</td>
<td>20 kbps</td>
<td>Tx/Rx to Earth</td>
</tr>
<tr>
<td></td>
<td>UHF</td>
<td>128 kbps</td>
<td>Tx/Rx to Mars</td>
</tr>
<tr>
<td></td>
<td>Ka-band</td>
<td>85 kbps (max)</td>
<td>Tx to Earth</td>
</tr>
<tr>
<td>Mars Express (ESA)</td>
<td>X-band</td>
<td>230 kbps</td>
<td>Tx to Earth</td>
</tr>
<tr>
<td></td>
<td>S-band</td>
<td>&lt; 2 kbps</td>
<td>Rx from Earth</td>
</tr>
<tr>
<td></td>
<td>UHF</td>
<td>128 kbps</td>
<td>Tx/Rx to Mars</td>
</tr>
<tr>
<td>Mars Odyssey</td>
<td>X-band</td>
<td>128 kbps</td>
<td>Tx/Rx to Earth</td>
</tr>
<tr>
<td></td>
<td>UHF</td>
<td>128 kbps</td>
<td>Tx/Rx to Mars</td>
</tr>
</tbody>
</table>
Asset-Specific Communications
Nominal Specifications
## Antenna Technology Summary

### Surface Communications Assets

<table>
<thead>
<tr>
<th>Surface/Surface Communications</th>
<th>Potential Frequencies</th>
<th>Comments/Specs</th>
<th>Desirable Antenna Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Astronaut EVA Suit</strong></td>
<td>UHF/VHF S-band</td>
<td>Data Services</td>
<td>• Miniature Antennas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Audio</td>
<td>• Multi-directional (to support mobility)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TT&amp;C*</td>
<td>• Wearable Antennas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SDTV Video</td>
<td>• Dipole/Monopole (omni-directional coverage)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HDTV Video</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biomedical Control*</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biomedical Monitoring*</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Limited power/space availability; UHF/S-Band surface comm. frequencies</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>*Must be reliable links</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reliable links require low BER</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Antennas should be small, efficient and wideband/multiband to accommodate desired frequencies and data services in a restricted space.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multiband Important for Software Defined Radio (SDR) to reduce size, weight and power (SWaP)</td>
<td></td>
</tr>
<tr>
<td><strong>Rovers</strong></td>
<td>UHF/VHF S-band</td>
<td>Mobile Nodes with data-intensive mission requirements for surface-based exploration.</td>
<td>• Phased Arrays (pitch/roll compensation)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Characterized by entities of moderate size and free to move about the lunar surface (e.g., rovers, pressurized vehicles, astronauts, robots)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tightly constrained by power, mass and volume.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Antennas should be low/self-powered, small, and efficient, and compatible with communication equipment that can provide high data rate coverage at short ranges (~1.5-3 km, horizon for the moon for EVA).</td>
<td></td>
</tr>
<tr>
<td><strong>Probes</strong></td>
<td>UHF/VHF S-band</td>
<td>Small Nodes: support fixed and mobile nodes, and connect to the network by wired or wireless interface.</td>
<td>• Retro-directive Antenna</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sensors, small probes, instruments and subsystems of very small size, limited power levels, and short range (~10 m) low data rate communications.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Antennas should be low/self-powered, small, and efficient.</td>
<td></td>
</tr>
<tr>
<td><strong>Habitat/Surface Relays</strong></td>
<td>HF (OTH Propagation)</td>
<td>Large, fixed nodes: Serves as base for surface activities.</td>
<td>• Deployable Antennas</td>
</tr>
<tr>
<td></td>
<td>S-band X-band</td>
<td>Centralized Hub/Habitat for immediate area coverage</td>
<td>• Multi-directional coverage (to support mobility)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transmission of data to surface and space assets</td>
<td>• Smart/reconfigurables</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can support larger communication hardware and higher data rates over long distances.</td>
<td>• Multi-beam antennas (to support connectivity to different nodes)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Smart/reconfigurable antennas, multibeam antennas, lightweight deployable antennas are viable technologies (10-30 Km)</td>
<td>• Electrically &amp; physically small antennas</td>
</tr>
</tbody>
</table>
## Antenna Technology Summary

### Space Communication Assets

### Surface/Orbit Communications

<table>
<thead>
<tr>
<th>Potential Frequencies</th>
<th>Comments/Specs</th>
<th>Desirable Antenna Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CEV</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-band</td>
<td>Robotic Lunar Exploration Program (RLEP-1,2)</td>
<td>Phased Arrays</td>
</tr>
<tr>
<td>X-band</td>
<td>Lunar Reconnaissance Orbiter (LRO) (RLEP-1)</td>
<td>Wideband/multiband and conformal antennas</td>
</tr>
<tr>
<td>Ku/Ka-band</td>
<td>Crew Launch Vehicle (CLV)</td>
<td>Frequency selective surface (FSS) antennas</td>
</tr>
<tr>
<td></td>
<td>Crew Exploration Vehicle (CEV)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Antenna Requirements: Conformal, Reconfigurable or Multiband antennas, phased arrays (most likely S-band for Initial CEV, with omni or patch antennas).</td>
<td></td>
</tr>
<tr>
<td><strong>Satellites Systems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UHF</td>
<td>Relay satellites (around the moon (e.g., LRO after its initial prospecting mission, it could be elevated to elliptical orbit for relay purposes); around Mars; etc.)</td>
<td>Gimbaled Dish</td>
</tr>
<tr>
<td>S-band</td>
<td>Relay satellites (L1/L2)</td>
<td>Phased Arrays</td>
</tr>
<tr>
<td>X-band</td>
<td>The intended orbit will drive the type of antenna technology.</td>
<td>Deployable Antennas</td>
</tr>
<tr>
<td>Ku/Ka-band</td>
<td>In Orbit: Gimbaled dish? (slew rate driven), reflectarrays, phased array antennas, deployable/inflatable arrays</td>
<td>Multi-Beam antennas</td>
</tr>
<tr>
<td></td>
<td>Mobile Nodes with data-intensive mission requirements for surface-based exploration.</td>
<td>High Gain Antennas</td>
</tr>
<tr>
<td></td>
<td>Characterized by entities of moderate size and free to move about the lunar surface (e.g., rovers, pressurized vehicles, astronauts, robots)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tightly constrained by power, mass and volume.</td>
<td></td>
</tr>
<tr>
<td><strong>Rovers</strong></td>
<td>Small Nodes: support fixed and mobile nodes, and connect to the network by wired or wireless interface.</td>
<td>Miniaturized antennas</td>
</tr>
<tr>
<td></td>
<td>Sensors, small probes, instruments and subsystems of very small size, limited power levels, and short range (~10 m) low data rate communications.</td>
<td>Phased Arrays</td>
</tr>
<tr>
<td></td>
<td>Antennas should be low/self-powered, small, and efficient.</td>
<td></td>
</tr>
<tr>
<td><strong>Probes</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Relevant Antenna Technologies
GRC Antenna Research Heritage

- **Rcv Array / Boeing 20 GHz (MASCOM)**
- **Rcv Array / Boeing 20 GHz (ICAPA)**
- **Rcv Array / Martin 20 GHz**
- **Rcv/Xmt Array AATT/WINCOM Ku-Band / Boeing**
- **Multibeam Antenna**
- **Ka-band 256 Element Boeing Phased Array**
- **Reflectarray Antenna SCDS 615 Element Prototype + Ka-Band Space Qualifiable**
- **Rcv Array / Boeing 20 GHz (MASCOM)**
- **Rcv Array / Boeing 20 GHz (ICAPA)**
- **Rcv Array / Martin 20 GHz**
- **Rcv/Xmt Array AATT/WINCOM Ku-Band / Boeing**
- **Phased Array Prototypes Technology Demonstrations, and SATCOM On-The-Move**
- **Advanced Phased Array Concepts and Materials + Large Gossamer Deployable Antennas**
- **Space Quality Phased Arrays, Deployable Antennas with Articulated Feeds, Space Experiments, Lunar and Mars Exploration and Earth Science**
Technology Readiness Level

- **TRL 1**: Basic principles observed and reported
- **TRL 2**: Technology concept and/or application formulated
- **TRL 3**: Analytical and experimental critical function and/or characteristic proof-of-concept
- **TRL 4**: Component and/or breadboard validation in laboratory environment
- **TRL 5**: Component and/or breadboard validation in relevant environment
- **TRL 6**: System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)
- **TRL 7**: System prototype demonstration in a space environment
- **TRL 8**: Actual system completed and “flight qualified” through test and demonstration (Ground or Flight)
- **TRL 9**: Actual system “flight proven” through successful mission operations
Large Aperture Deployable Antennas
(X-, and Ka-Band: TRL 4)

Benefits
• Reduced mass (~1 kg/m²)
• Low fabrication costs
• High packaging efficiencies (as high as 50:1)
• Proven performance at S-Band & L-Band frequencies

Issues
• Stringent RMS surface accuracy requirements at high frequencies (i.e. Ka-Band)
• Development of reliable deployment mechanisms
• Thermal response
• Rigidization

Potential Applications
• Deep space relay station concept
• Backup satellite antenna systems
• Erectable surface communications relays
“Terrestrial” Deployable Antennas

Four 1-meter inflatable membrane antennas under assembly and pedestal array concept

Training sequence

RF-to-BB and PLL

Adaptive algorithm

Training sequence

Error

RF-to-BB and PLL

RF-to-BB and PLL
4 Element Inflatable Antenna Array
August 2005

- Georgia Tech “GCATT” building adaptive array algorithm verification Experiment with the SAC-C satellite August 22-25, 2005
Large Aperture Deployable Antennas  
(X-band: TRL 3)

Hybrid Inflatable Antenna

- Combines traditional fixed parabolic dish with an inflatable reflector annulus
- Redundant system prevents “all-or-nothing” scenarios
- Based on novel shape memory composite structure
- High packing efficiency

(1) Low cost fabrication and inflation of an annulus antenna
(2) Overall surface accuracy 1 mm
(3) Negligible gravity effects
(4) Elimination of large curve distortions across the reflector surface (i.e. Hencky curve)
Phased Array Antennas
(K-, and Ka-Band: TRL 9)

**Benefits**
- Electrically Steerable
- Conformal
- Graceful degradation
- Multi-Beam
- Fast Scanning/acquisition
- S-, X-, Ku-, K-, and Ka-Band

**Issues**
- Low MMIC efficiency (thermal management problems)
- Cost per module
- FOV (limited to +/- 60°)

**Potential Applications**
- CLV, CEV
- Robotic Rovers
- Satellite Systems
- Surface Communications
GRC Low Cost Electrically Steerable Array Antenna Road Map

1990 - 1998

Past Significant GRC Ka-band phased array developments

- 32 element breadboard proof-of-concept
- Mechanically steered Array proof-of-concept
- 91 element breadboard proof-of-concept

2000 - 2006

Parameter | Forward Link | Return Link
---|---|---
Ka-band Frequency Plan | 30 | 20
Channel Bandwidth | 9.6Kbps (NB) 1.5Mbps (WB) | 9.6 - 128 Kbps (NB) 1.5Mbps (WB)

Parameter | Forward Link | Return Link
---|---|---
Channel Bandwidth | 50 MHz | 650 MHz

- 1990-1998 : Funding Source ACTS
- 2000-2003 : Funding Source SCDS
256-Element Ka-Band Phased Array Antenna (PAA)

Summary  Array Specification (Boeing)

<table>
<thead>
<tr>
<th>Array Number of Elements</th>
<th>256 Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequencies</td>
<td>25.5-27.5 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>&gt; 1 GHz</td>
</tr>
<tr>
<td>Gain (CP)</td>
<td>28 dBi</td>
</tr>
<tr>
<td>Antenna EIRP</td>
<td>Peak 36.5 dBW</td>
</tr>
<tr>
<td>3 dB - Beam width</td>
<td>@ 60 Degrees 33 dBW</td>
</tr>
<tr>
<td>Antenna</td>
<td>Nominal 5 Degrees</td>
</tr>
<tr>
<td>RF Input Drive Level</td>
<td>130 mW (1 beam)</td>
</tr>
<tr>
<td>Array Total DC Power</td>
<td>90 Watts (1 beam)</td>
</tr>
<tr>
<td>DC Power Supply</td>
<td>+28 V</td>
</tr>
<tr>
<td></td>
<td>(± 7V)</td>
</tr>
</tbody>
</table>

256 Elements Array (Boeing)
Two Principal Planes Cuts Antenna
(Beam 1)

LHCP w/RHCP off, phi = 0
(Measured by Boeing)

Far-field amplitude of RLOFF_15.nsi

- AR < 1.1
- Directivity (estimated from pattern measurements) : 27.6 dBi
- Directivity (predicted no M-coupling) : 28.2 dBi
- Beamwidth: 6.7 deg

LHCP w/RHCP off, phi = 90
(Measured by Boeing)

Far-field amplitude of RLOFF_15.nsi

- AR < 1.1
- Directivity (estimated from pattern measurements) : 27.6 dBi
- Directivity (predicted no M-coupling) : 28.2 dBi
- Beamwidth: 7.7 deg
Ferroelectric Reflectarray Development
(K-band: TRL 3)

- **Potential Applications**
  - Satellite Antenna Systems
  - Ground-based Deep Space Network Array

- **Benefits**
  - High efficiency
  - Zero manifold loss
  - Electronically steerable
  - Lightweight, planar reflector

**EIRP (dBW)**

- **Reflectarray**
- **MMIC**

**Gain (dB)**

- **Ferroelectric Reflectarray**
- **Direct Radiating MMIC Array**

**Expected**

- **SQR of Number of Radiating Elements**

**Power Consumed (W)**

- **0**
- **500**
- **1500**
- **2000**

19 GHz 615 Element Prototype

≈ 28 cm Active Diameter
Next Generation Deep Space Network Concept

- Achieving required Ka-band surface tolerance difficult for very large apertures
- Large antenna cost proportional to \((\text{diameter})^2\)
- Advances in Digital Signal Processing make arraying a large number of “small” antennas feasible

GRC Antenna Farm Concept Based on Reflectarray Technology

Flat panels containing printed microstrip patch radiator arrays assembled into circular aperture to save weight and manufacturing cost. Benefits cascade because of simplified gimbal drive systems and reduced maintenance.
Multi-Beam Antennas
(S-, Ka-band: TRL 4)

Potential Applications
- Smart Antenna Systems
- Ground-based Communications (i.e., Habitat, Relays)
- Satellite Constellations

Benefits
- No manifold losses
- Capable of multiple beams
- Pseudo conformal

Collaboration with Dr. Z. Popovic University of Colorado, Boulder
SMALL ANTENNAS

(TRL 1-3)
Antenna Technologies for Future NASA Exploration Missions

Description and Objectives:

- Develop new design concepts and candidate miniature antenna structures capable of supporting the communication needs of future Lunar and Martian surface exploration activities.
- Develop compact, self-powering, self-oscillating communications package utilizing miniature antenna development effort.
- Perform trade-off studies among in-house miniature antenna designs and state-of-the-art commercial off-the-shelf (COTS) antennas for Exploration Missions.
- Develop processing algorithm for a randomly distributed network of Lunar surface sensors to enable a surface-to-orbit communication without the need of a Lunar surface base station.

Application: Lunar Surface Exploration Missions

- Robots and Rovers
- Surface Sensors/Probes
- Astronaut EVA
- Nanosatellites

Technology Products:

- Folded Hilbert Curve Fractal Antenna
- Compact Microstrip Monopole Antenna
- Two-layer Sector Miniature Antenna
- MEMS Integrated Reconfigurable Antenna
- Solar Cell Integrated Antenna
- Miniatuized antenna for Bio-MEMS Sensors
- Beam formed by Randomly Located Antennas/Sensors
- Sensor Web Interconnections
- Random Sensor Network Array

- TRL_{in} = 2
- TRL_{out} = 3
folded Hilbert Curve Fractal Antenna (fHCFA)

**Design Concept:**
- Fractal antenna geometry allows for unique wideband/multi-band operation due to pattern-repetitive nature of fractal shapes. Geometry also allows for antenna miniaturization, similar to meander lines, but with more efficient space utilization.
- Develop an antenna based on a 3rd order Hilbert curve geometry folded upon itself (multilayer) to further decrease antenna footprint.

**Results:**
- fHCFA exhibits multi-resonant behavior.
- Two modes of operation with optimized radiation pattern diversity for surface-to-surface and surface-to-orbit communications at relevant frequencies without switching.

---

Compact Microstrip Monopole Antenna (CMMA)

**Design Concept:**
- Reduce operating frequency of patch antenna through use of grounding wall and increased perimeter with a compact footprint.
- Adjust for inherent decrease in directivity with vertical wall.
- Combine a microstrip patch with a 3-dimensional structure to attain a highly directive, broadband, compact antenna which radiates like a miniature monopole antenna.

\[ \frac{\lambda}{12} ! \]

**Results:**
- End-fire radiation pattern allows for lunar surface-to-surface communications with an antenna structure 1/6\(^{th}\) the size of a monopole antenna.

**Solar Cell Integrated Antennas**

**Design Concept:**
- Integrate solar cell, local oscillator and miniature antenna for complete, compact, self-powering communications system.
- Integrated antenna radiating element/oscillator generates its own RF power.
- Demonstrate prototype active oscillator solar cell array antenna modules capable of beam steering based on multi-junction GaAs solar cell and oscillator antenna technologies.
- Foundation for larger aperture, beam-steerable antennas using coupled oscillator approach.
- The proposed system will enable the development of low-cost, lightweight satellites with high directivity communication links for Flexible Access Networks.

**Miniature Antenna**
Provides compact structure to transmit RF signal

**Local Oscillator**
Provides modulation of frequency carrier for relevant data transmission

**Solar Cell**
Provides power for communications system. Can be integrated on antenna layer, or on oscillator layer.

**Results:**
Fabricated integrated antenna/oscillator using Duroid RT 6010 microwave laminate (dielectric constant = 10.2), with pseudomorphic high electron mobility gallium arsenide transistors

\[ TRL_{in} = 2 \]
\[ TRL_{out} = 3 \]
Concept:

- Develop electrically small antennas and self-healing, adaptive decision algorithms for coherent signal detection and transmission from an array of randomly distributed planetary sensors. The sensor array will configure itself to form a beam in a general direction that can be intercepted by a passing orbiter or directed to a particular satellite or planetary surface-based receiver.

- Develop miniaturized antennas and beam forming algorithm for random sensor arrays that enable the sensor to work together to communicate their data to remote collection sites without the need for a base station.

- Develop miniaturized antennas with moderate bandwidths for planetary surface communications between remote sites sensors or orbiters.

- The technology is intended to enable low-risk sensing and monitoring missions in hostile planetary and/or atmospheric environments.

- Development of distributed Bayesian Algorithm based fault tolerant, self organizing random sensor detection

Prototype Miniaturized Antenna

Approach allows randomly distributed Lunar surface sensors to work together as an array and thus enhances communication capabilities by decreasing the probability of single point communication failure.

Projected Network Operation - Flowchart

1. "Pod" of low-cost sensors launched from orbiter and scattered randomly on the surface.

2. Beacon signal sent from orbiter to sensors used for calibration and time synchronization.

3. Sensors form surface-level network to determine relative locations of sensors to make calculations for beamforming and to exchange data.

4. Signal processing algorithms on the sensors determine the relative phase and amplitude of each sensor's signal to form a beam in the direction of the orbiter.

5. Sensors cooperatively send data back to orbiter without the need for single-point of failure base station on the surface.

Simulated Beam forming Achieved Using Bayesian Estimation Method For a Random Sensor Array
RF Telemetry System for Implantable Bio-MEMS Sensors

(TRL 3-4)

- NASA seeks to develop telemetry based implantable sensing systems to monitor the physiological parameters of humans during space flights.
- A novel miniature inductor and pick-up antenna for contact-less powering and RF telemetry from implantable Bio-MEMS sensors has been developed.

Measured received relative signal strength as a function of frequency:
(a) Pick-up antenna at a height of 5 cm. (b) Pick-up antenna at a height of 10 cm.
Miniature Antennas
(TRL 2)

- Artificially manufacturable
  Metamaterials: Magnetic
  Photonic Crystals (MPC).

- These MPCs exhibit the
  following properties:

  (a) considerable slow down of
      incoming wave, resulting in
      frozen mode.

  (b) huge amplitude increase.

  (c) minimal reflection at the
      free space interface.

  (d) large effective dielectric
      constant, thus enabling
      miniaturization of the
      embedded elements.

Collaboration with Dr. John Volakis and Mr. Jeff Kula (OSU)
Conclusions

- By 2030, 1 Gbps deep space data rates desired. Choosing the proper antenna technology for future NASA exploration missions will rely on: data rate requirements, available frequencies, available space and power, and desired asset-specific services. Likewise, efficiency, mass, and cost will drive decisions.

- Viable antenna technologies should be scalable and flexible for evolving communications architecture.

- Enabling technologies include: large aperture deployable/inflatable antennas (reduce space/payload mass), multibeam antennas (reduce power consumption), reconfigurable antennas (reduce space), low loss phased arrays (conformal/graceful degradation), and efficient miniature antennas (reduce space/power).

- Efficient miniature antennas will play a critical role in future surface communications assets (e.g., SDR radios) where available space and power place stringent requirements on mobile communications systems at the envisioned UHF/VHF/S-band surface comm. frequencies (i.e., astronaut suits, probes, rovers).