Antenna Technologies for NASA Applications

This presentation addresses the efforts being performed at GRC to develop antenna technology in support of NASA's Exploration Vision. In particular, the presentation discusses the communications architecture asset-specific data services, as well as wide area coverage, high gain, low mass deployable antennas. Phased array antennas as well as electrically small, lightweight, low power, multifunctional antennas will be also discussed.

Antenna Technologies for NASA Applications

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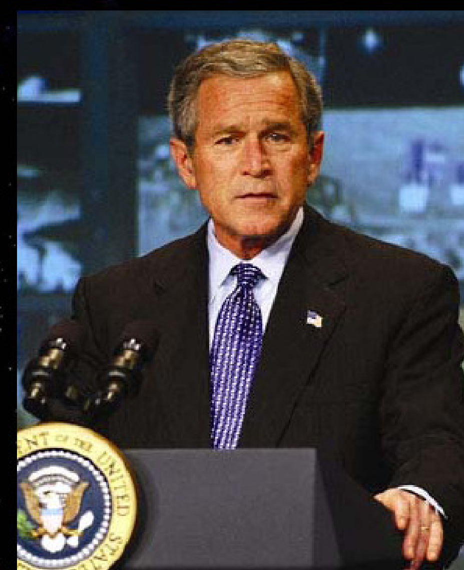
IDGA’s Military Antenna Systems Conference
Westin Arlington Gateway, Arlington, VA
September 19-20, 2006

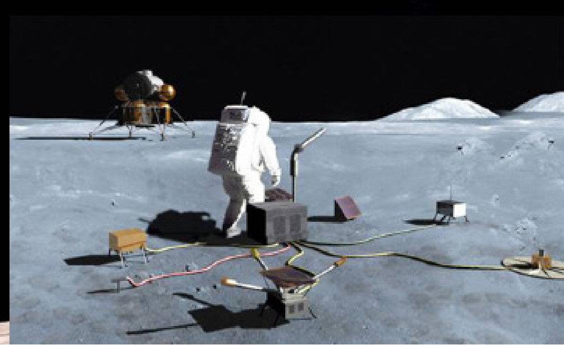
Outline of Presentation

- The Vision for Space Exploration
- Communications Architecture for Exploration
- Asset-Specific Communications Requirements
- Technology Development at Glenn Research Center
- Summary

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





"It is time for America to take the next steps.

Today I announce a new plan to explore space and extend a human presence across our solar system. We will begin the effort quickly, using existing programs and personnel. We'll make steady progress – one mission, one voyage, one landing at a time"

President George W. Bush – January 14, 2004

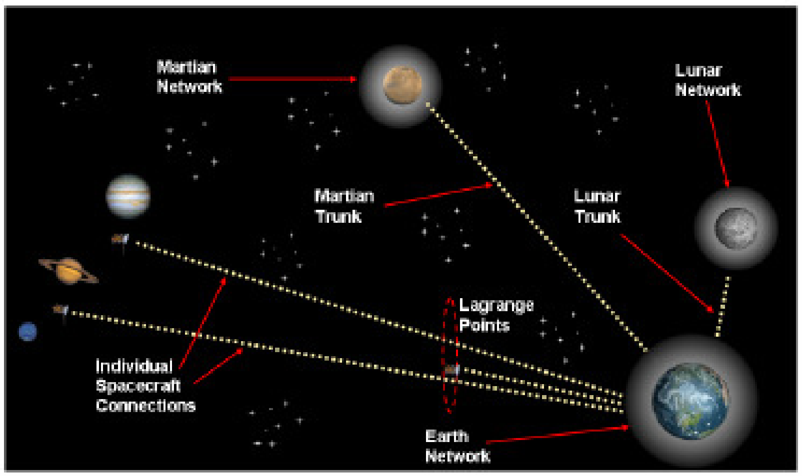
Communications Architecture

Assessment of Existing NASA Communications Capability

- Limited lunar coverage
- Existing Earth-based Tracking and Data Relay Satellite System (TDRSS) can presently provide limited Low Earth Orbit (LEO) and translunar backup systems for critical communications in lunar vicinity due to area coverage limitations
- Ground Networks (GN) can provide LEO and translunar short pass duration communications
- Large aperture Deep Space Network (DSN) antennas (26m, 34m, 70m) can provide excellent high-rate coverage in lunar vicinity
- Limited Mars communications data rates and numbers of connections
- Limited precision Mars navigation capability

Space Communication Architecture Working Group (SCAWG)

NASA Space Communication and Navigation Architecture Recommendations for 2005-2030



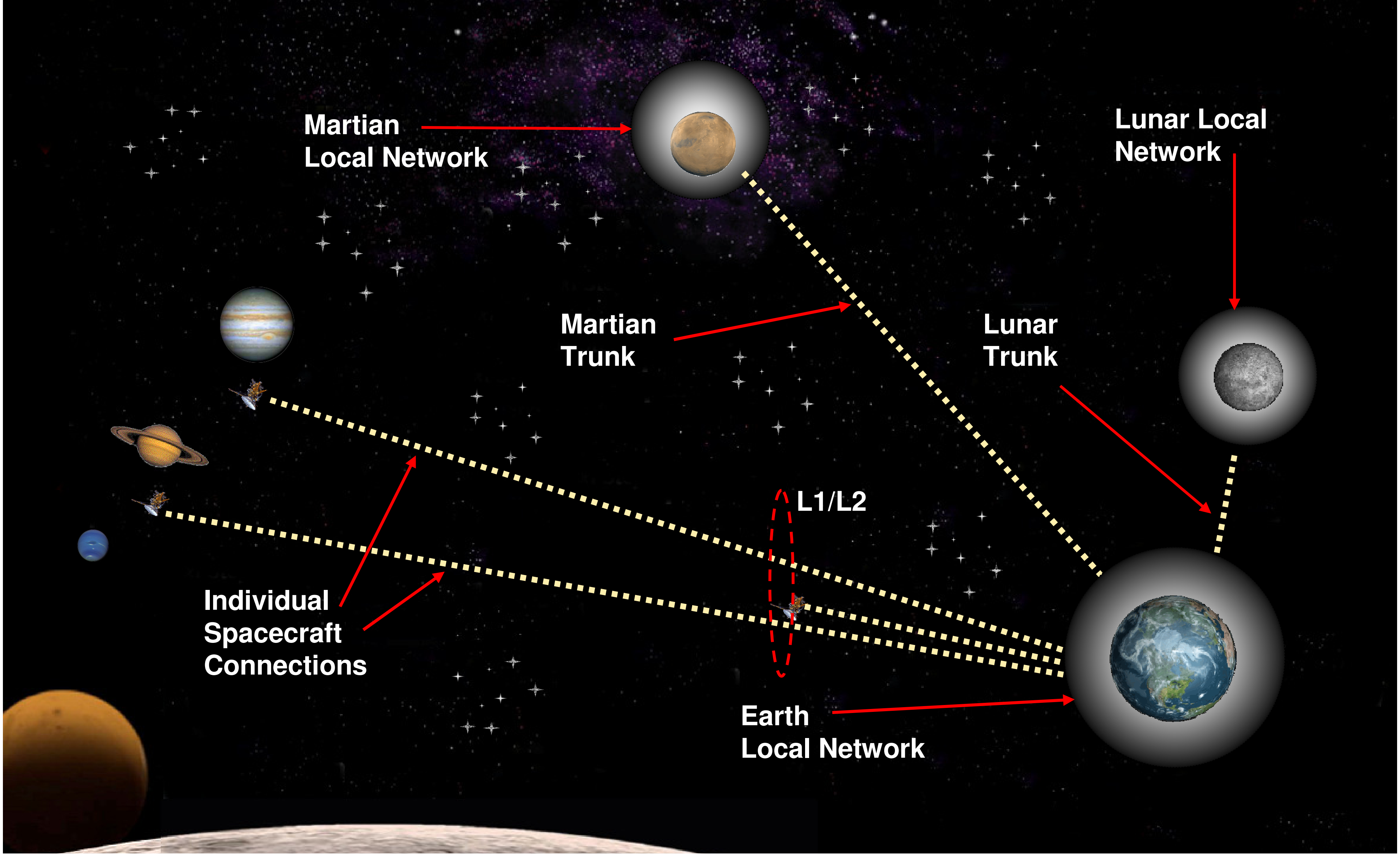
15 May 2006

Final Report

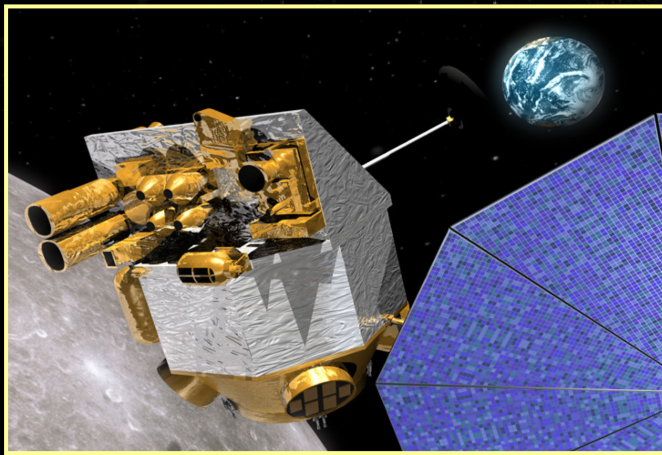
Space Communications Architecture Final Report is available.

https://www.spacecomm.nasa.gov/spacecom/

Top Level Conceptual Communication Architecture ~2030

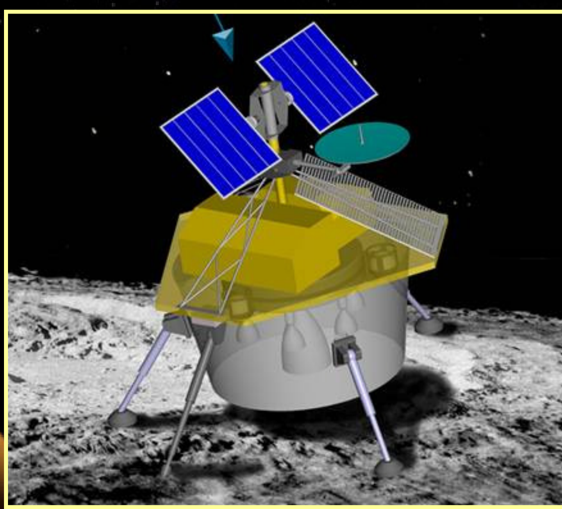


Lunar Communications Assets



Lunar Reconnaissance Orbiter (LRO)

UHF&S-Band	**Tx/Rx to Moon** *125 bps to 256 kbps*
S-Band	**Tx/Rx direct to Earth** *2.186 Mbps QPSK*
Ka-Band	**Tx to Earth** *>100 Mbps*

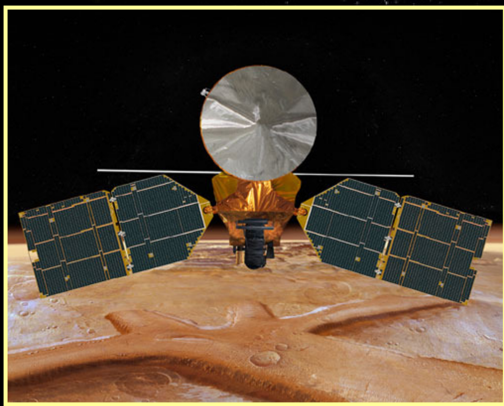


Robotic Lunar Lander

VHF/UHF*	**Surface Comm.** *(Data Rates: TBD)*
S-Band*	**Surface Comm.** **Tx/Rx relay to Earth** *(Data Rates: TBD)*
Ka-Band*	**Tx to Earth** *(Data Rates: TBD)*

** Probable communications frequencies*

Mars Communications Assets



Mars Reconnaissance Orbiter (MRO)

UHF	Tx/Rx to Mars *100 kbps - 1 Mbps*
X-Band	Tx/Rx to Earth *300 kbps*
Ka-Band	Tx to Earth *5 Mbps BPSK*

Arrival Date: March 10, 2006

Mars Odyssey

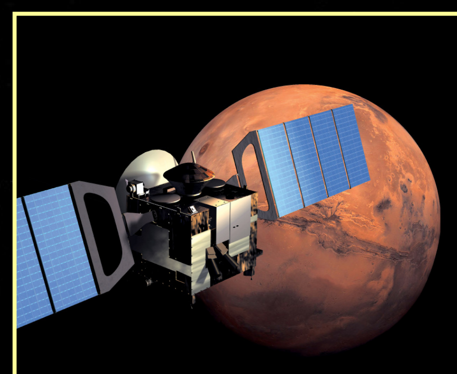
UHF	Tx/Rx to Mars *128 kbps*
X-Band	Tx/Rx to Earth *128 kbps*

Arrived October 24, 2001

Mars Global Surveyor (MGS)

UHF	Tx/Rx to Mars *128 kbps*
X-Band	Tx/Rx to Earth *20 kbps*
Ka-Band	Tx to Earth *85 kbps (max)*

Arrived September 12, 1997



Mars Express (ESA)

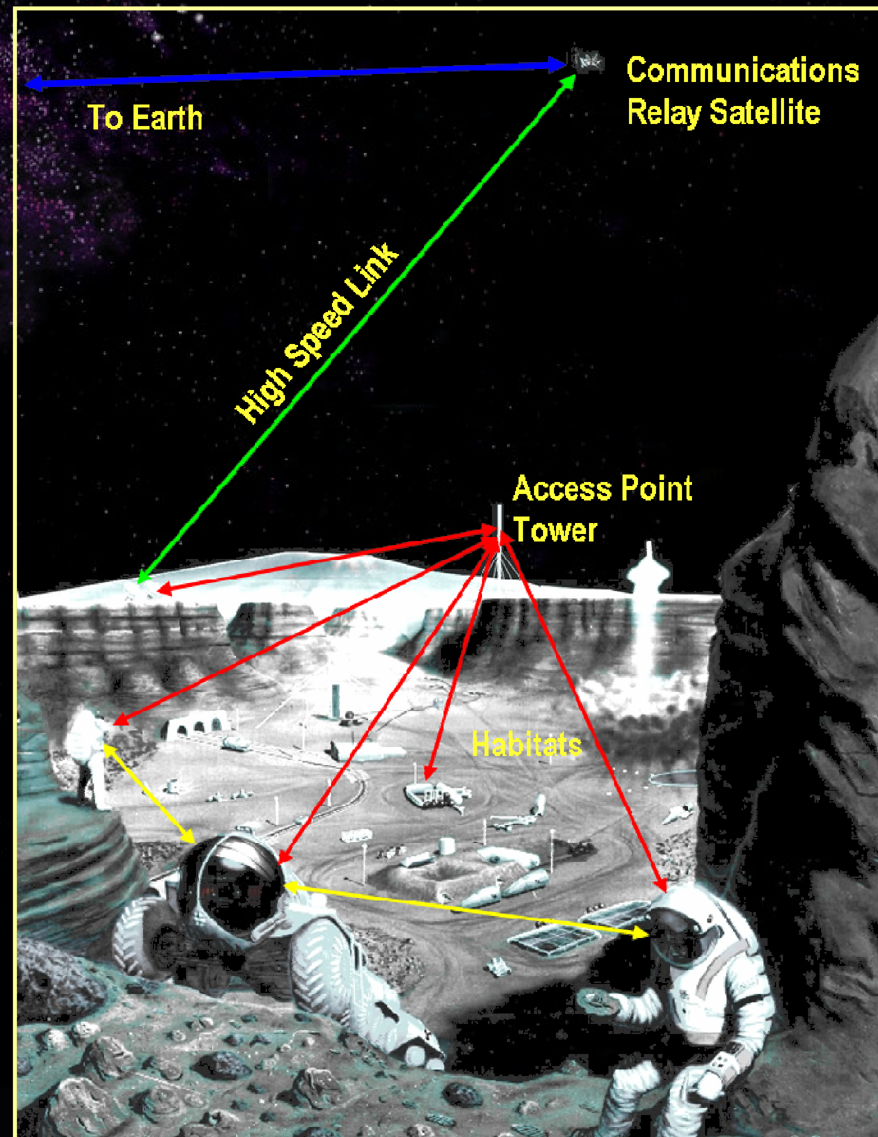
UHF	Tx/Rx to Mars *128 kbps*
S-Band	Rx from Earth *up to 2 kbps*
X-Band	Tx to Earth *230 kbps*

Arrived December 25, 2003

Asset-Specific Communications Nominal Specifications

Surface Communications Architecture (~2030)

- Surface assets (e.g., nodes) communicate via each other and a centralized hub
- Surface Wireless Local Area Network (SWLAN) infrastructure to connect astronauts with rovers, probes, habitat, and each other
- Ad-hoc proximity networking amongst assets
- Access point (relay) towers to extend communication capabilities range



Surface Communications Assets

Astronaut EVA Suit

Data Services	
Audio*	8-64 kbps/channel (at least 4 channels)
TT&C*	< 100 kbps
SDTV Video	6 Mbps
HDTV Video	19 Mbps
Biomedical Control*	70 kbps
Biomedical Monitoring*	122 kpbs

*Must be Reliable Links

Limited power/space availability

UHF/S-Band surface comm. frequencies

- ***Reliable links require low BER***
- ***Antennas should be small, efficient, and wideband/multiband to accommodate desired frequencies and data services in a restricted space.***
- ***Multiband important for Software Defined Ratio (SDR) to reduce size, weight, and Power (SWaP)***

Surface Communications Assets

Habitat

- Mobile Nodes with data-intensive mission requirements for surface-based exploration.
- Characterized by entities of moderate size and free to move about the lunar surface (e.g., rovers, pressurized vehicles, astronauts, robots)
- Tightly constrained by power, mass and volume.

➢ ***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).***

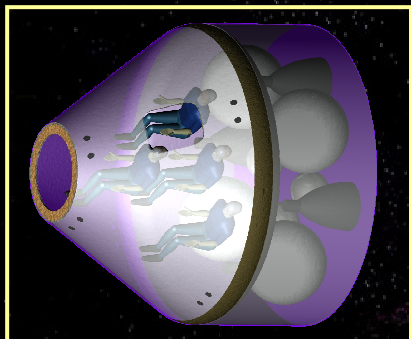
- Small Nodes: support fixed and mobile nodes, and connect to the network by wired or wireless interface.
- Sensors, small probes, instruments and subsystems of very small size, limited power levels, and short range (~10 m) low data rate communications.

➢ ***Antennas should be low/self-powered, small, and efficient.***

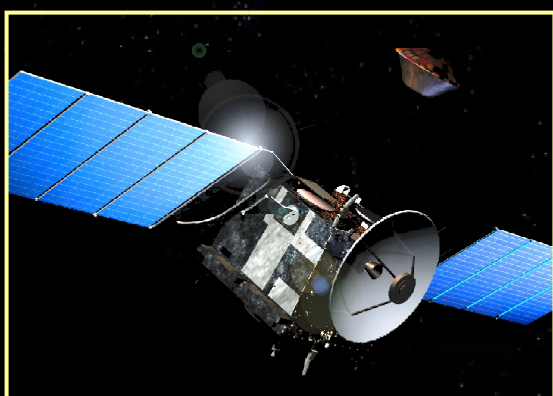
- Large, fixed nodes: Serves as base for surface activities.
- Centralized Hub/Habitat for immediate area coverage
- Transmission of data to surface and space assets
- Can support larger communication hardware and higher data rates over long distances.

➢ ***Smart/reconfigurable antennas, multibeam antennas, lightweight deployable antennas are viable technologies (10-30 Km)***

Space Communications Assets



Crew Exploration Vehicle (CEV)



Satellite Systems

- Robotic Lunar Exploration Program (RLEP-1,2)
- Lunar Reconnaissance Orbiter (LRO) (RLEP-1)
- Crew Launch Vehicle (CLV)
- Crew Exploration Vehicle (CEV)

➢ ***Antenna Requirements: Conformal, Reconfigurable or Multiband antennas, phased arrays (most likely S-band for Initial CEV, with omni or patch antennas).***

- 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.)
- Relay satellites (L1/L2)
- The intended orbit will drive the type of antenna technology.

➢ ***In Orbit: Gimbaled dish? (slew rate driven), reflectarrays, phased array antennas, deployable/inflatable arrays***

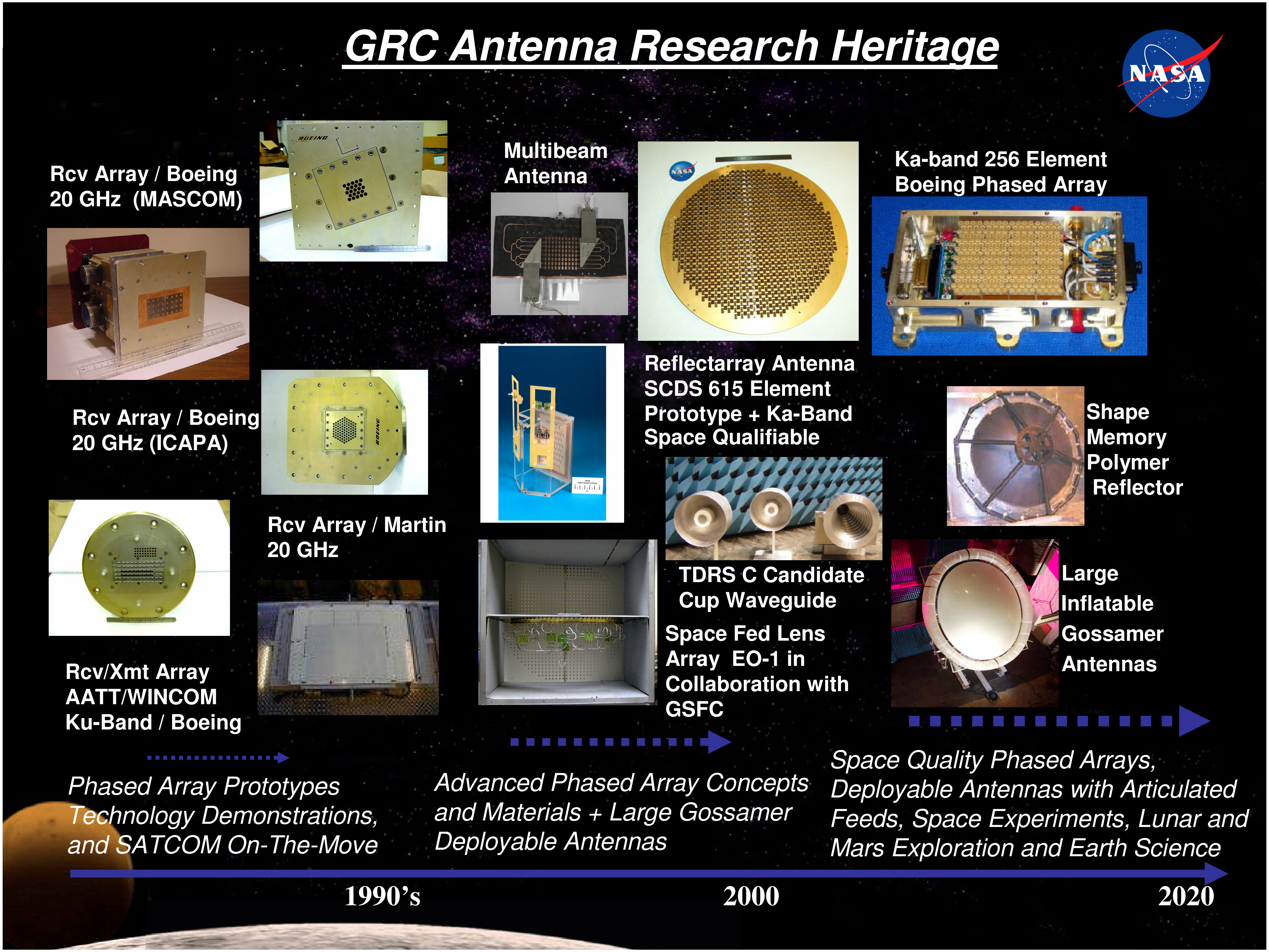
Antenna Technology Summary

Surface/ Surface Communications	Potential Frequencies	Desirable Antenna Technologies	
EVA Suit	**UHF/VHF** **S-band**	• Miniature Antennas • Multi-directional (to support mobility) • Wearable Antennas	• Dipole/Monopole (omni-directional coverage)
Rovers	**UHF/VHF** **S-band**	• Miniature Antennas • Omni antennas	• Phased Arrays (pitch/roll compensation)
Probes	**UHF/VHF** **S-band**	• Miniature Antennas • Dielectric Resonator Antennas • Wideband Antennas	• Solar Cell Integrated Antennas • Retrodirective Antenna
Habitat/Surface Relays	**HF (OTH Propagation)** **S-band** **X-band**	• Deployable Antennas • Multi-directional coverage (to support mobility) • Smart/reconfigurable Antennas	• Multi-beam Antennas (to support connectivity to different nodes) • Citizen band antennas

Antenna Technology Summary

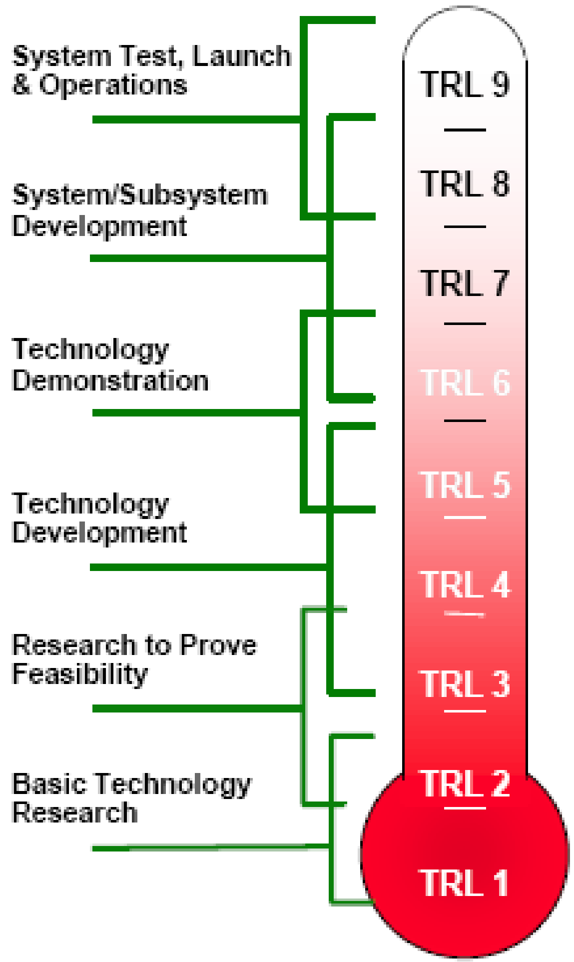
Surface/Orbit Communications	Potential Frequencies	Desirable Antenna Technologies
CEV	S-band X-band Ku/Ka-band	• Phased Arrays • Wideband/Multiband • Conformal Antennas • Frequency Selective Surface (FSS) Antennas
Satellites	UHF S-band X-band Ku/Ka-band	• Gimbaled Dish • Phased Arrays • Deployable Antennas • Multi-Beam antennas • High Gain Antennas
Rovers	UHF S-band	• Miniature Antennas • Phased Arrays
Probes	UHF	• Miniature Antennas • Solar Cell Integrated Antennas • Patch antennas • Retro-directive Antenna

Antenna Technology Development at Glenn Research Center



GRC Antenna Research Heritage
NASA
Rcv Array / Boeing
20 GHz (MASCOM)
Multibeam
Antenna
Ka-band 256 Element
Boeing Phased Array
Rcv Array / Boeing
20 GHz (ICAPA)
Reflectarray Antenna
SCDS 615 Element
Prototype + Ka-Band
Space Qualifiable
Shape
Memory
Polymer
Reflector
Rcv Array / Martin
20 GHz
TDRS C Candidate
Cup Waveguide
Space Fed Lens
Array EO-1 in
Collaboration with
GSFC
Large
Inflatable
Gossamer
Antennas
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
1990's
2000
2020

Technology Readiness Level



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

Large Aperture Deployable Antennas
(X-, and Ka-Band: TRL 4)

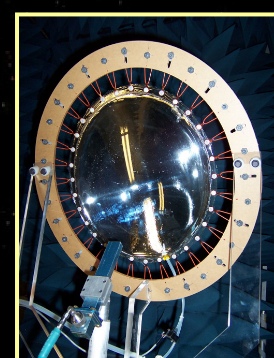
Benefits
- Reduced mass (~1 kg/m^2)
- Low fabrication costs
- High packaging efficiencies (as high as 50:1)
- Proven performance at S-Band & L-Band frequencies

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

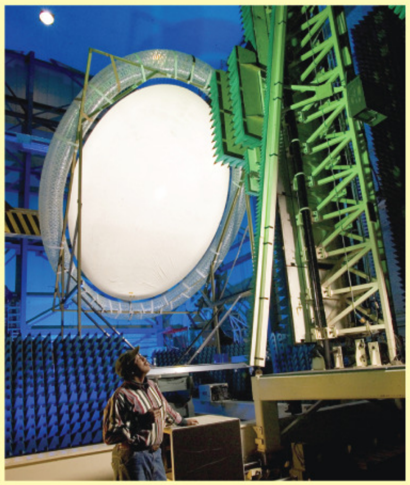
2.5 m “Beach Ball” Antenna


4 x 6 m offset parabolic

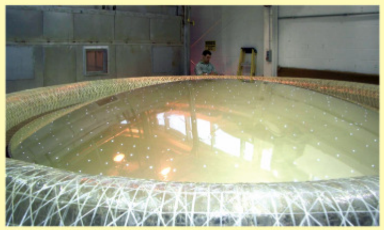

0.3 m Parabolic Antenna

Large Aperture Inflatable Antennas

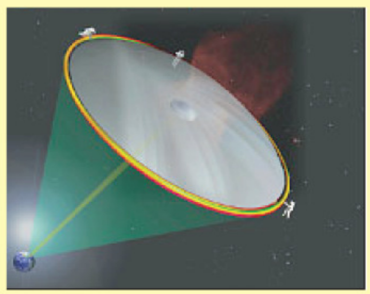
Space Applications



4- by 6-m inflatable offset parabolic membrane antenna test in GRC near-field facility

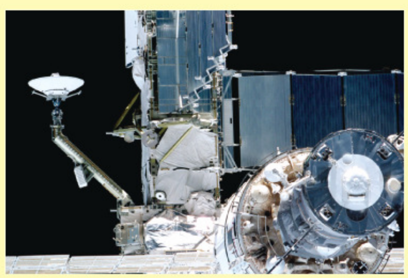


4- by 6-m inflatable offset parabolic membrane antenna inflation test (human in the background)



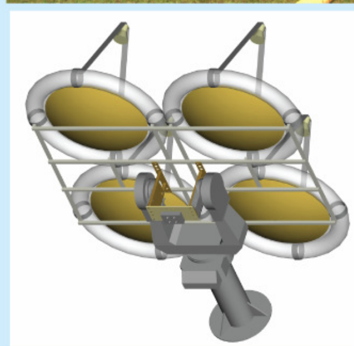
Deep-space relay station concept

Overhead photograph of 4- by 6-m inflatable reflector in GRC near field facility

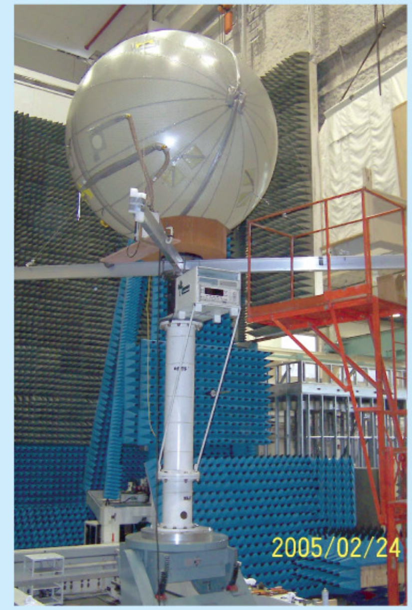


Backup 2-m inflatable Cassegrain reflector for ISS Ku-band system

Surface Applications



Low-cost tracking ground station experiment in collaboration with Goddard Space Flight Center planned for May 2005

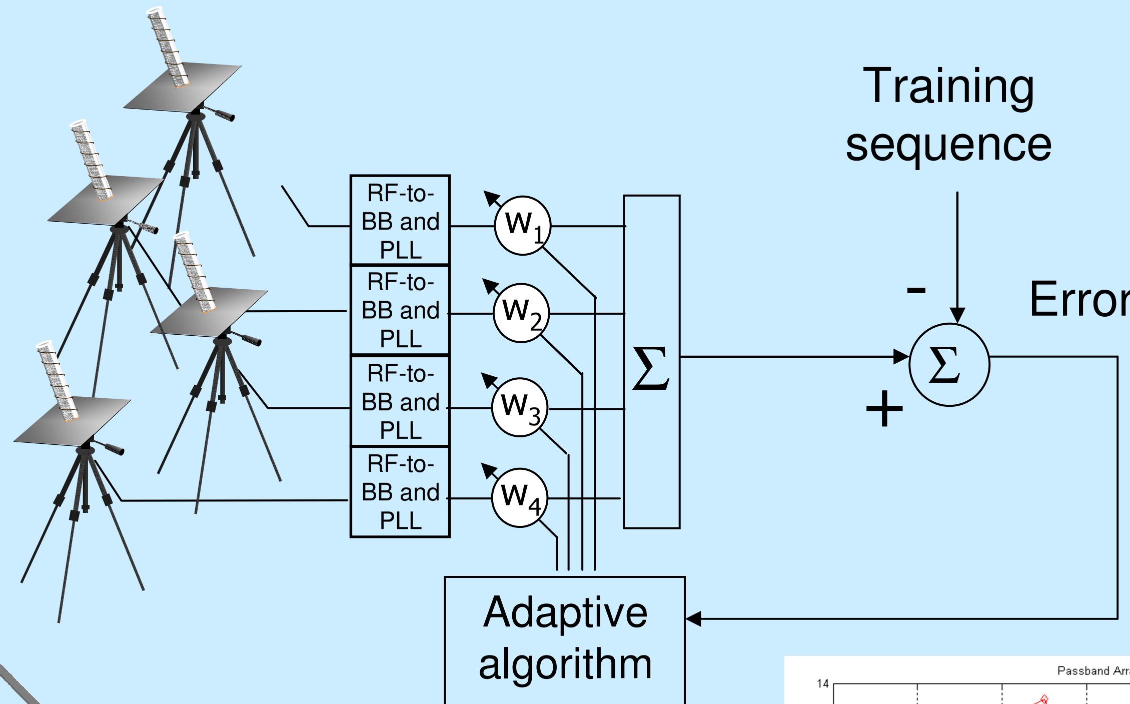


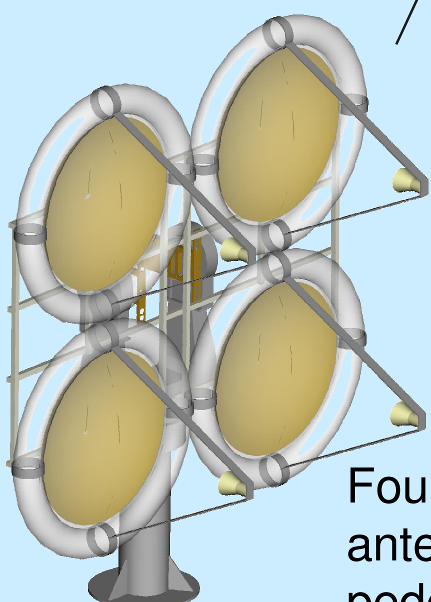
2.5-m inflatable membrane antenna in inflatable radome for ground applications

Goals:

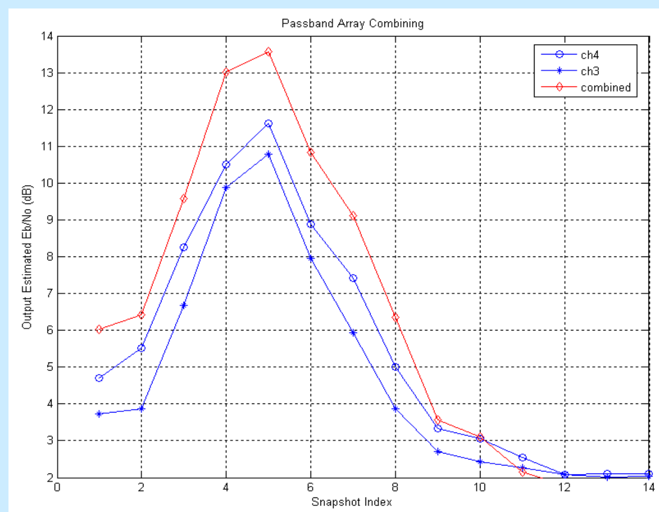
- Develop large, lightweight reflector antennas with areal densities <0.75 kg/m^2, for Lunar, Mars, and deep-space relay exploration applications.
- Develop rigidization techniques (e.g., ultraviolet curing) to eliminate the need for makeup inflation gas.
- Demonstrate a ratio package to deploy volume greater than 1:75.
- Demonstrate quick deployment of large apertures for ground-based and planetary surface applications.

"Terrestrial" Deployable Antennas





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



4 Element Inflatable Antenna Array

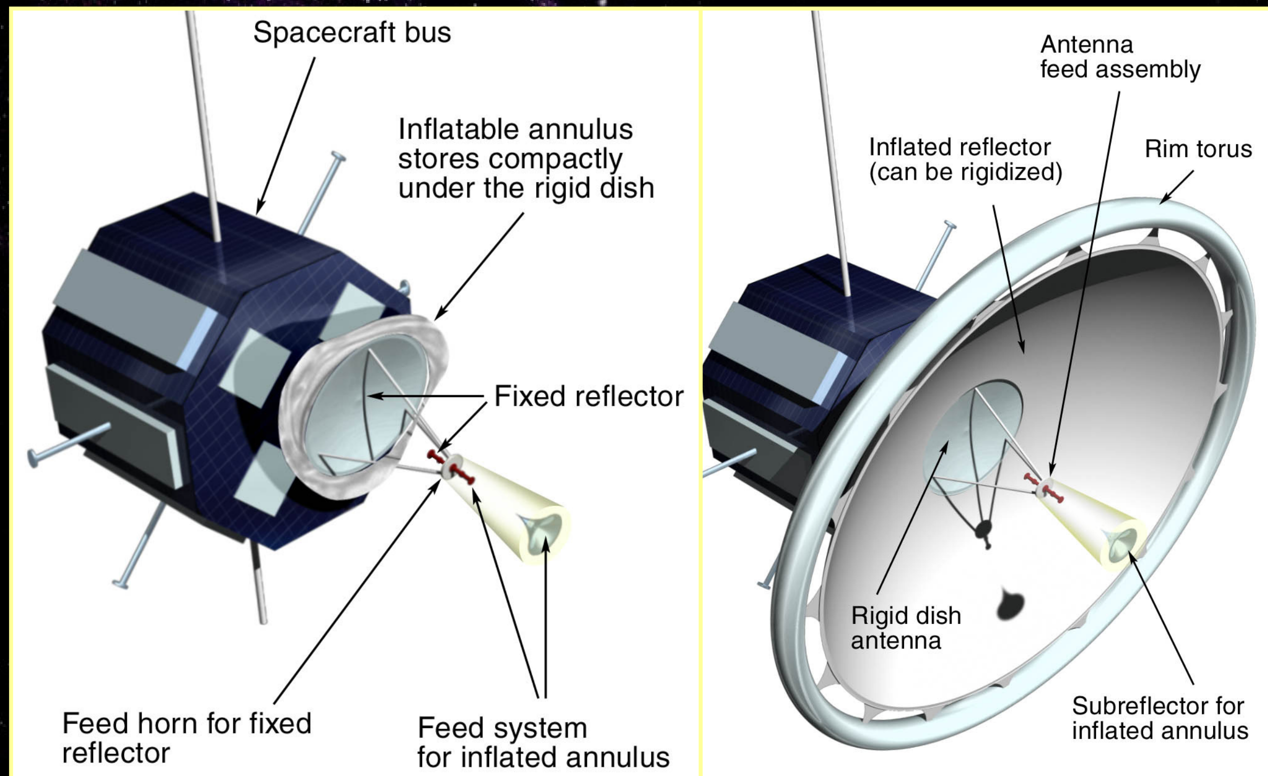
August 2005

- 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**

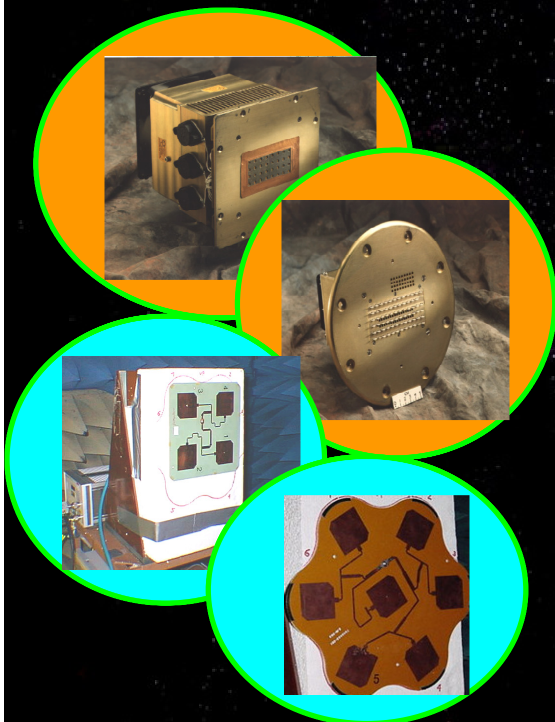


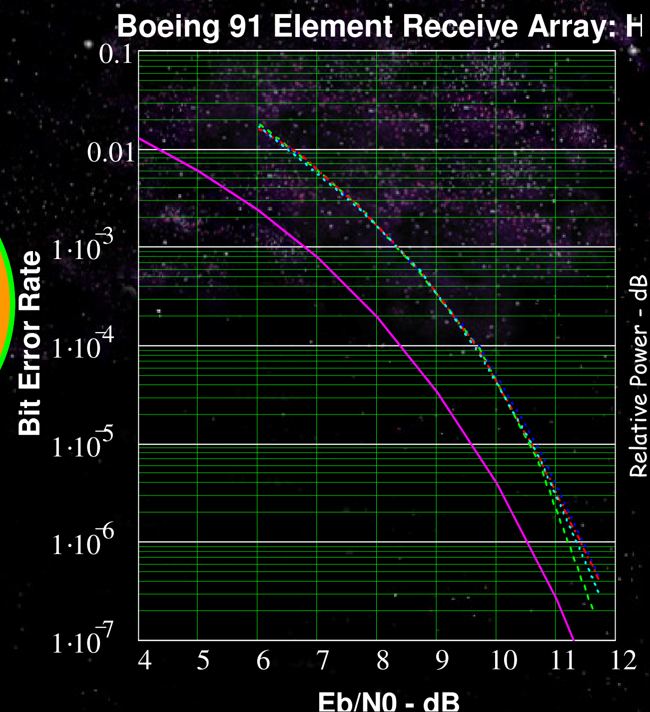
JHU/APL under NASA Grant

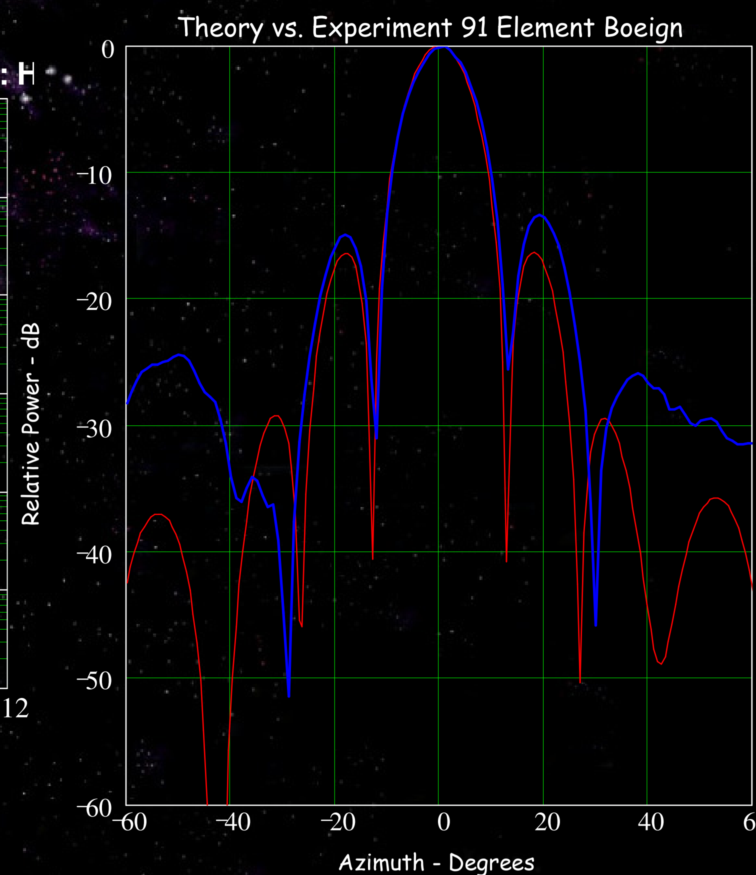
(1) Low cost fabrication and inflation of an annulus antenna
(2) Overall surface accuracy 1 mm
(3) Negligible gravity effects
(4) Elimination of large curve distortions across the reflector surface (i.e. Hencky curve)

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

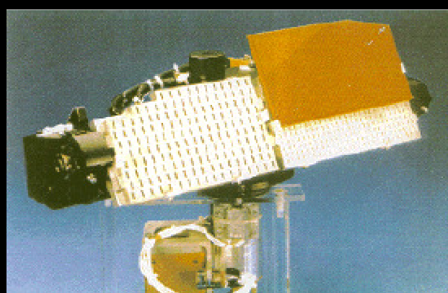
Issues
- Low MMIC efficiency (thermal management problems)
- Cost per module
- FOV (limited to +/- 60°)

Potential Applications
- CLV, CEV
- Robotic Rovers
- Satellite Systems
- Surface Communications

GRC Low Cost Electrically Steerable Array Antenna Road Map

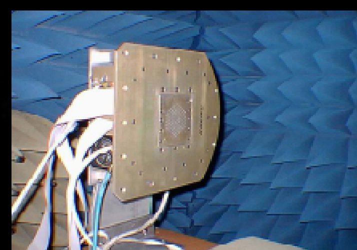
1990 - 1998

Past Significant GRC Ka-band phased array developments



Mechanically steered Array proof-of-concept

32 element breadboard proof-of-concept



91 element breadboard proof-of-concept

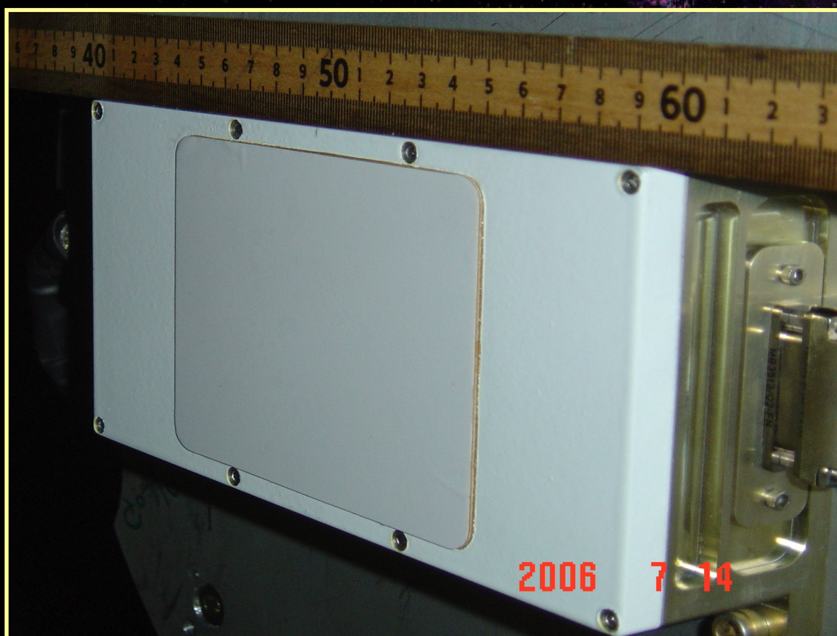
Parameter	Forward Link	Return Link
Ka-band Frequency Plan	30	20
Channel Bandwidth	9.6Kbps (NB) 1.5Mbps (WB)	9.6 – 128 Kbps (NB) 1.5Mbps (WB)

2000 - 2006

Parameter	Forward Link	Return Link
Ka-band Frequency Plan	22.555 – 23.545	25.545 – 27.195
Channel Bandwidth	50 MHz	650 MHz

- 1990-1998 : Funding Source ACTS
- 2000-2003 : Funding Source SCDS

256-Element Ka-Band Phased Array Antenna (PAA)



256 Elements Array (Boeing)

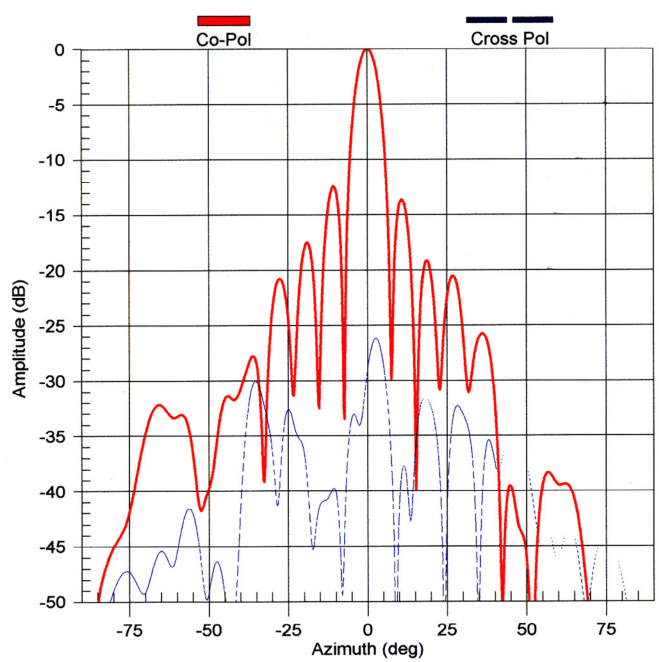
Summary Array Specification (Boeing)

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

Two Principal Planes Cuts Antenna

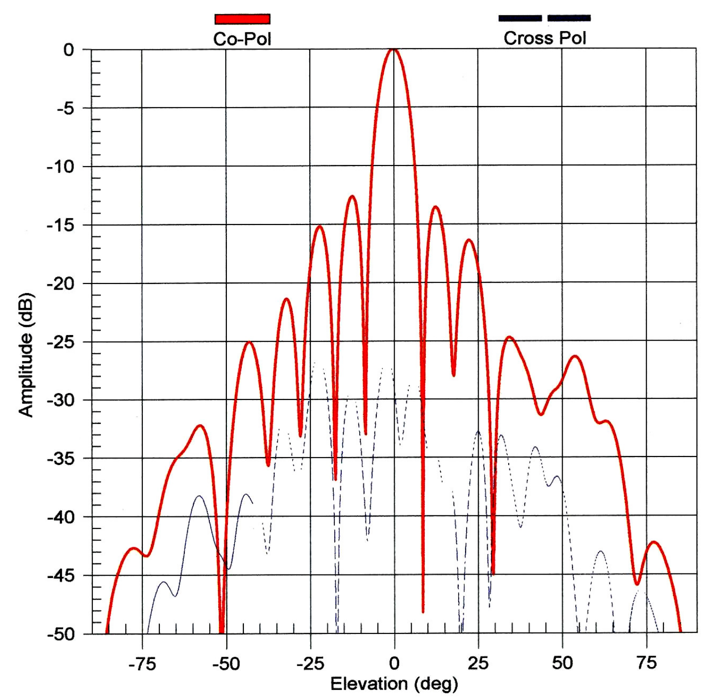
(Beam 1)

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



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

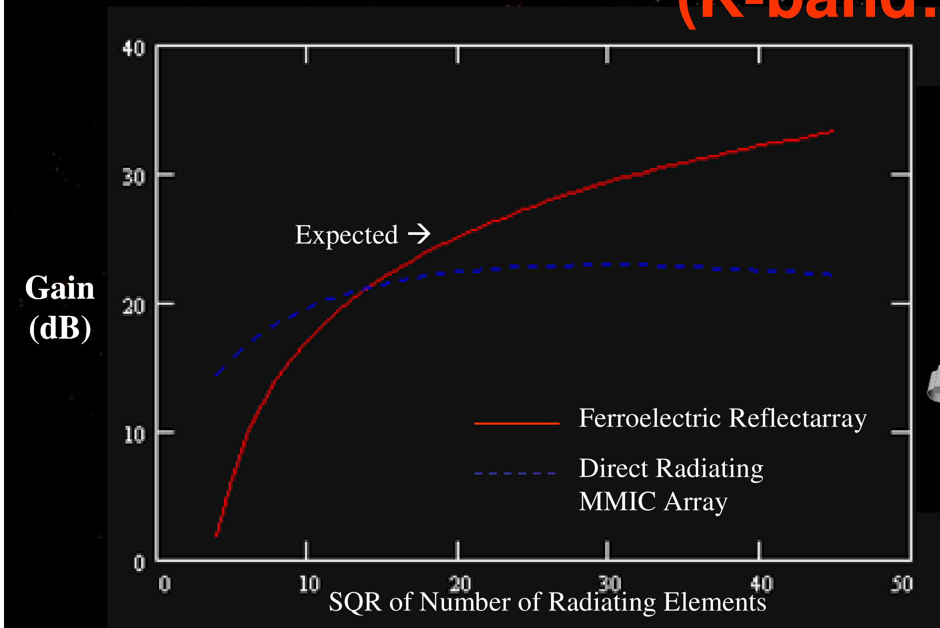
LHCP w/RHCP off, phi = 90 (Measured by Boeing)

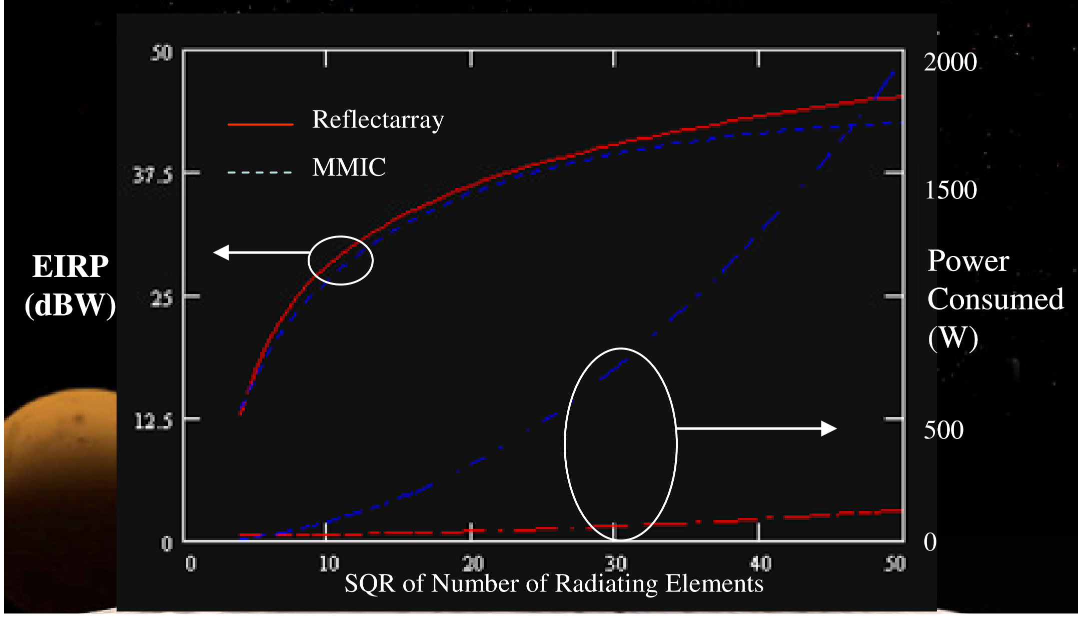


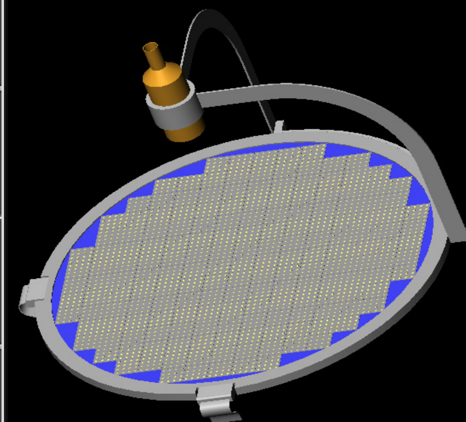
- AR < 1.1
- Directivity (estimated from pattern measurements) : 27.6 dBi
- Directivity (predicted no M-coupling) : 28.2 dBi
- Beamwidth: 7.7 deg

Ferroelectric Reflectarray Development

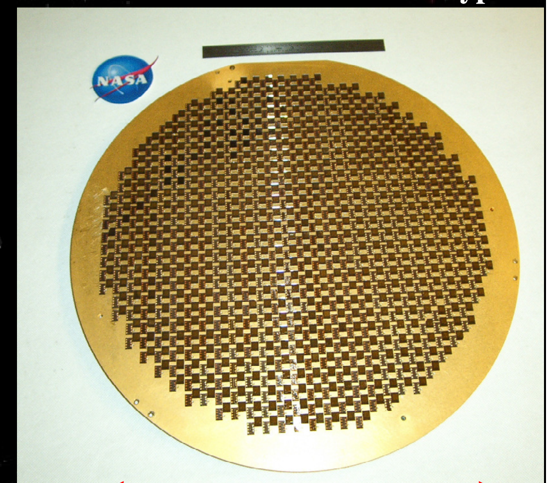
(K-band: TRL 3)



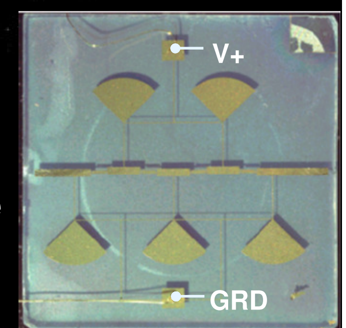




19 GHz 615 Element Prototype



≈ 28 cm Active Diameter



Benefits

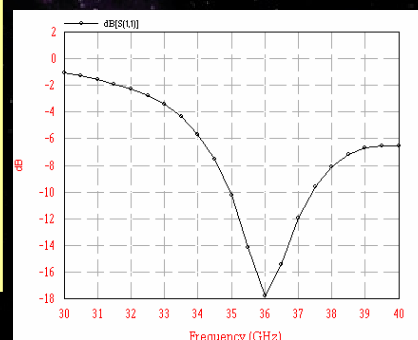
- High efficiency
- Zero manifold loss
- Electronically steerable
- Lightweight, planar reflector

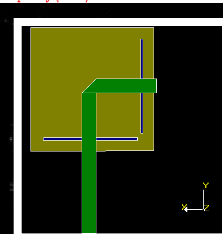
Potential Applications

- Satellite Antenna Systems
- Ground-based Deep Space Network Array

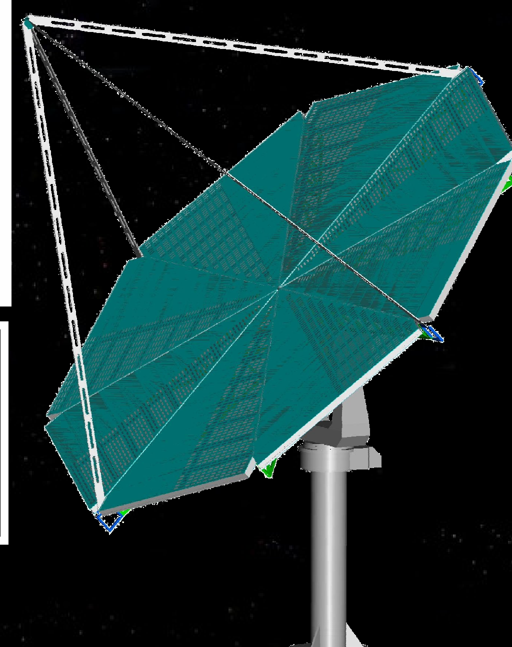
Next Generation Deep Space Network Concept

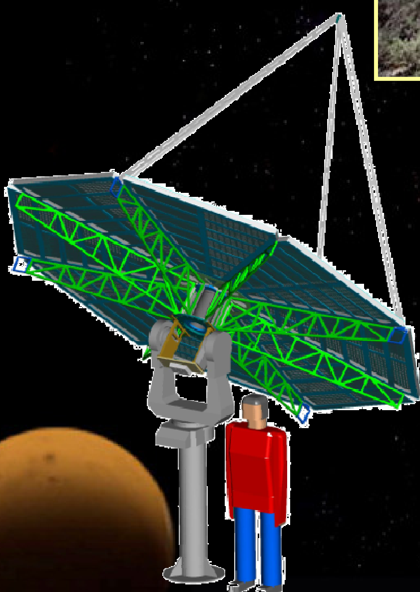
- Achieving required Ka-band surface tolerance difficult for very large apertures
- Large antenna cost proportional to (diameter)$^{>2}$
- Advances in Digital Signal Processing make arraying a large number of "small" antennas feasible





GRC Antenna Farm Concept
Based on Reflectarray Technology



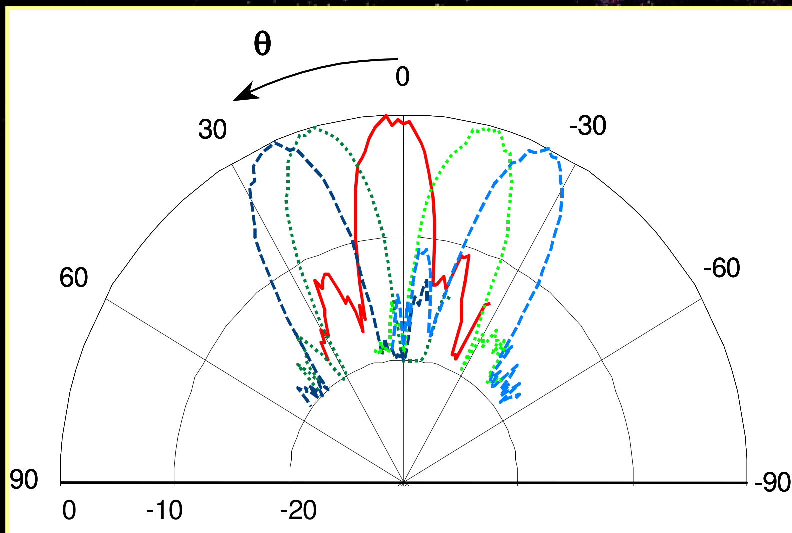


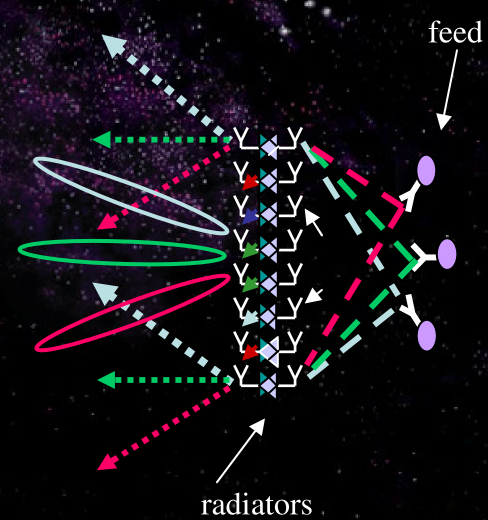
4 m prototype

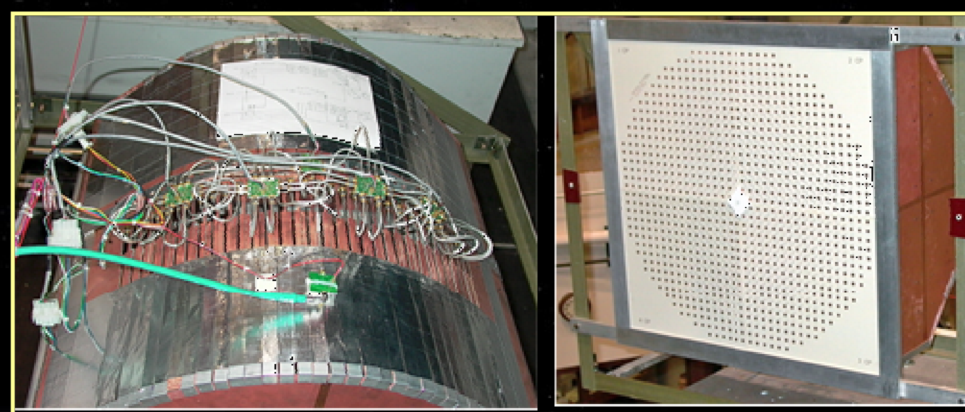
Flat panels containing printed microstrip patch radiator arrays assembled into circular aperture to save weight and manufacturing cost. Benefits cascade because of simplified gimbal drive systems and reduced maintenance

Multi-Beam Antennas

(S-, Ka-band: TRL 4)







Benefits

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

Potential Applications

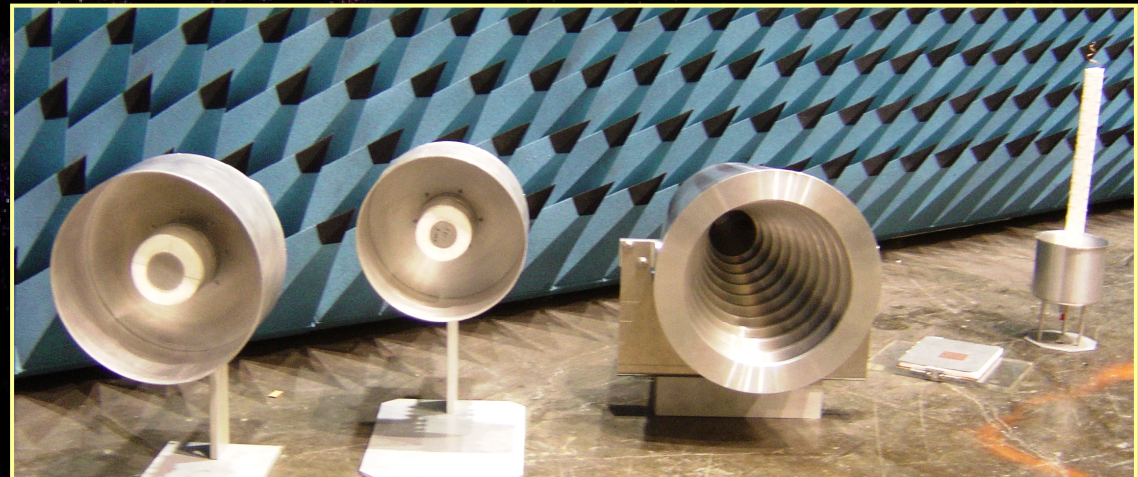
- Smart Antenna Systems
- Ground-based Communications (*i.e.*, Habitat, Relays)
- Satellite Constellations

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

TDRSS-C Antenna Development

(S-band: TRL 4)

- Next generation TDRSS to implement beam forming between S-band Single Access and Multiple Access antennas
- GRC responsible for antenna element design, construction and characterization of candidate antennas for next generation Multiple Access phased array



Potential Applications

- Satellite Antenna Systems

Specification	Bandwidth 2.0 – 2.3 GHz WB 2.2 – 2.3 GHz NB	Directivity >15 dBi Peak	Directivity at ± 20 deg. > 10 dBi	Axial Ratio < 5 dB ± 20 deg. LHCP,RHCP	Pol. Isolation < -20 dB	Return Loss < -20 dB Port Isolation < -10 dB	Mounting Footprint (Diameter)
Cup-Waveguide (Wideband)	NB Meets WB MEETS	Meets	Meets	Meets LHCP, RHCP	Meets	Meets	Meets 11.5 in
Cup-Waveguide (Narrowband)	NB Meets	Meets	Meets	Meets LHCP, RHCP	Meets	Meets	Meets 10.6 in
Horn	NB Meets	Meets	Meets	Meets LHCP, RHCP	Meets	Meets	DNM* 14.5 in
Helix	NB Meets	Meets	Meets	Meets LHCP	NA	Meets	Meets 6.0 in
Cup-Patch	WB Meets	Meets	Meets	Meets LHCP, RHCP	Meets	Meets	Meets 12.5 in

SMALL ANTENNAS
(TRL 1-3)

Antenna Technologies for Future NASA Exploration Missions

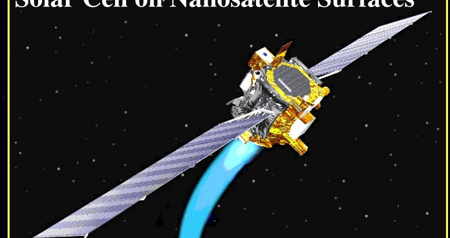
Description and Objectives:

- 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.

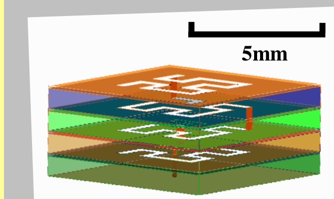
Application: Lunar Surface Exploration Missions

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

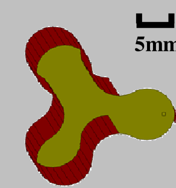
Solar Cell on Nanosatellte Surfaces



Technology Products:

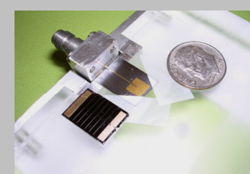


Folded Hilbert Curve Fractal Antenna

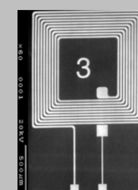


Compact Microstrip Monopole Antenna

TRL $_{in}$ = 2
TRL $_{out}$ = 3

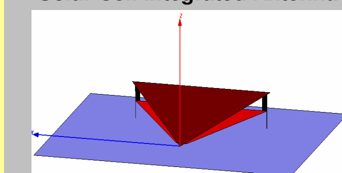


Solar Cell Integrated Antenna

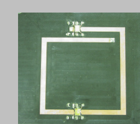


Miniaturized antenna for Bio-MEMS Sensors

TRL $_{in}$ = 2
TRL $_{out}$ = 3

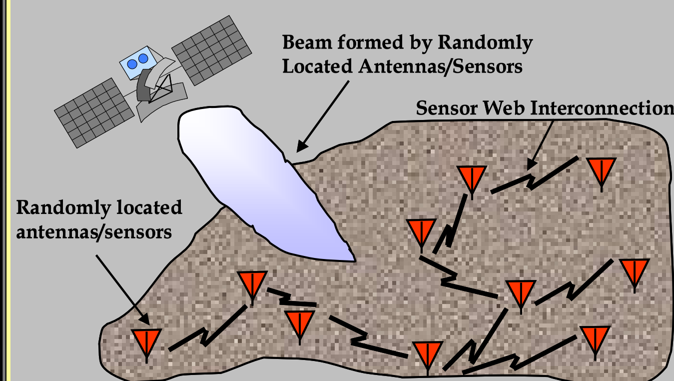


Two-layer Sector Miniature Antenna



MEMS Integrated Reconfigurable Antenna

TRL $_{in}$ = 2
TRL $_{out}$ = 3



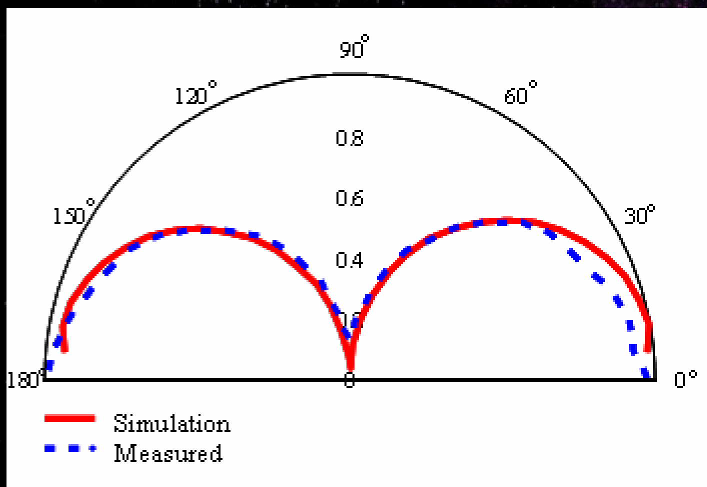
Random Sensor Network Array

TRL $_{in}$ = 2
TRL $_{out}$ = 3

Miniature Antennas

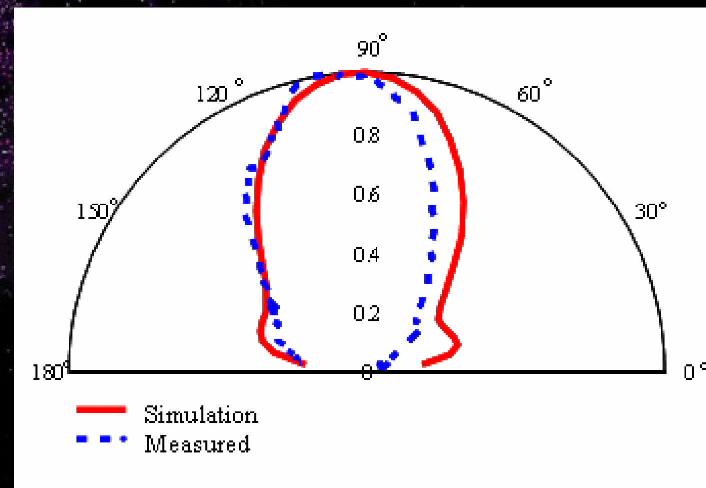
(S-, Ku-/Ka-band: TRL 3)

S-Band



Surface-to-Surface

Ku/Ka-Band



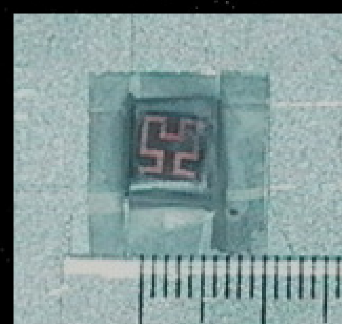
Surface-to-Orbit

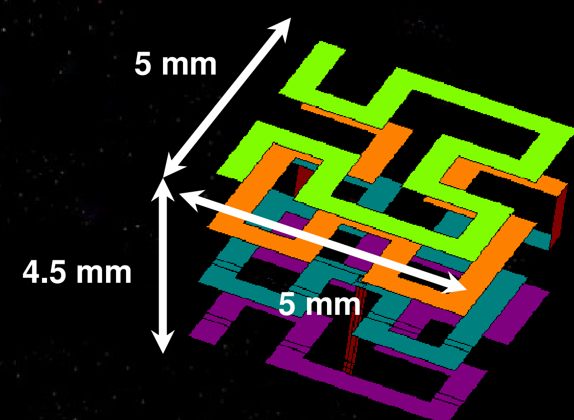
Benefits

- Provides optimal radiation patterns for surface-to-surface and surface-to-orbit communications at relevant frequencies without switches

Potential Applications

- Sensors/probes
- Robotic rovers
- Astronaut EVA



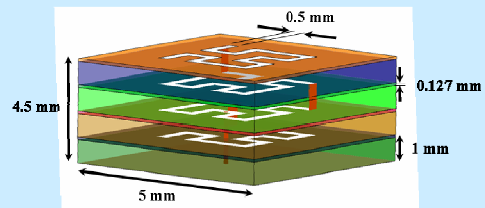


Folded Hilbert Curve Fractal Antenna

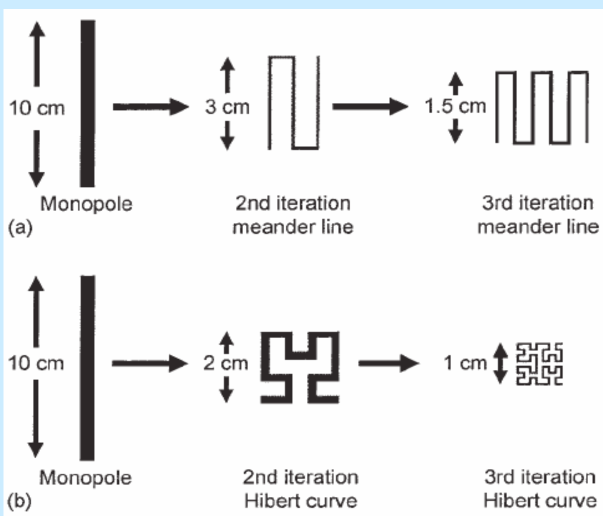
folded Hilbert Curve Fractal Antenna (fHCFA)

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.



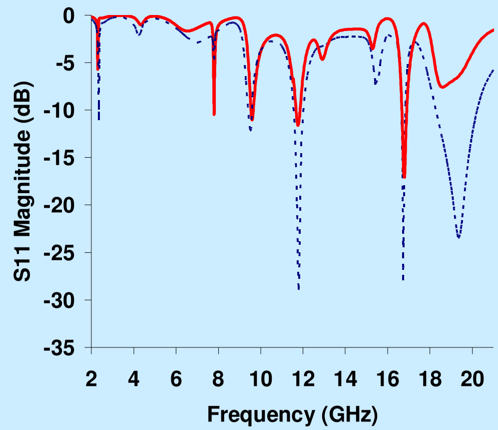
< λ/30 !

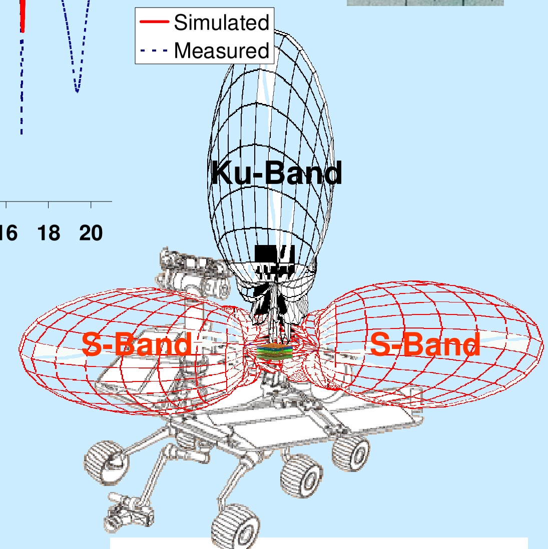


[1] James A. Nessel, Afroz J. Zaman, Félix A. Miranda, “A Miniaturized Antenna for Surface-to-Surface and Surface-to-Orbiter Applications,” Microwave and Optical Technology Letters, Vol. 48, No. 5, May 2006, pg. 859-862

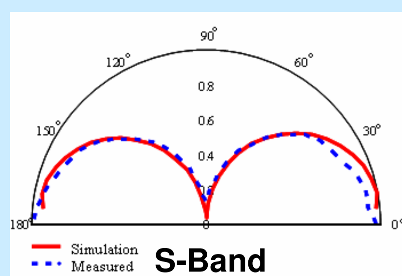
Results:

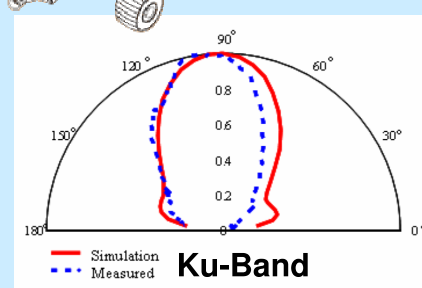
- fHCFA exhibits multi-resonant behavior.
- Two modes of operation with optimized radiation pattern diversity for surface-to-surface and surface-to-orbit communications at relevant frequencies without switching.





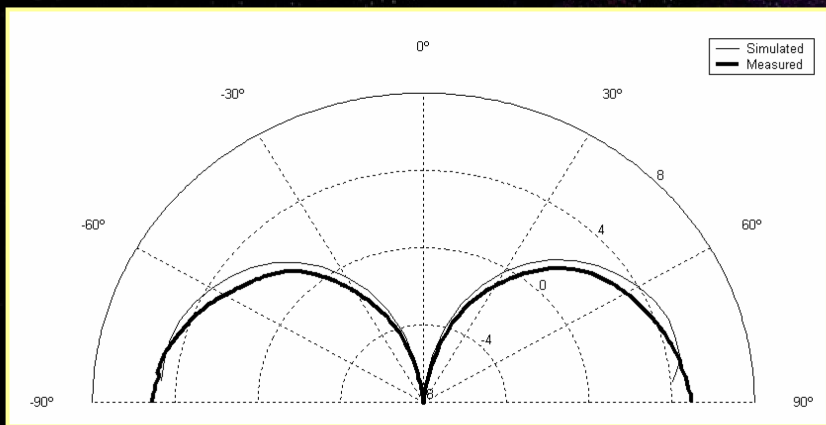
TRL $_{in}$ = 2
TRL $_{out}$ = 3



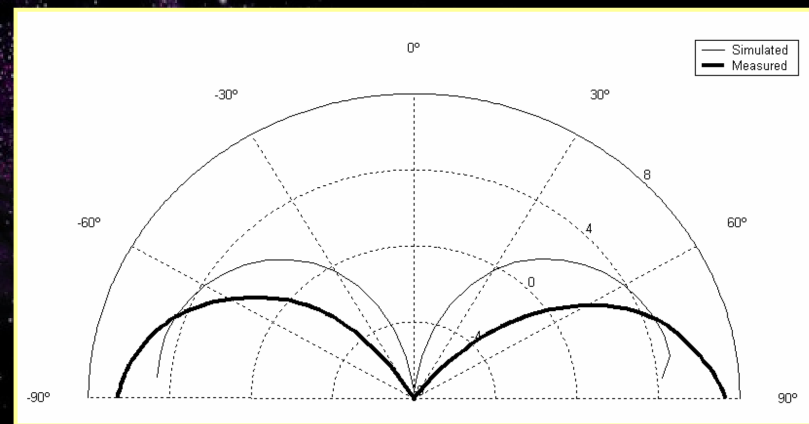


Miniature Antennas

(S-band: TRL 3)



E-plane Pattern



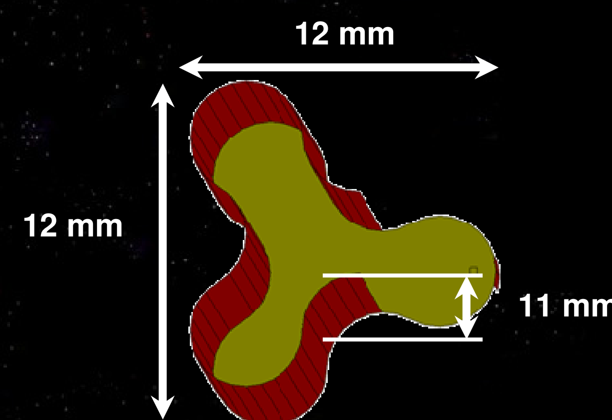
H-plane Pattern

Benefits

- Performance comparable to an S-band dipole, but at less than 1/6 the size

Potential Applications

- Sensors/probes
- Robotic rovers
- Astronaut EVA



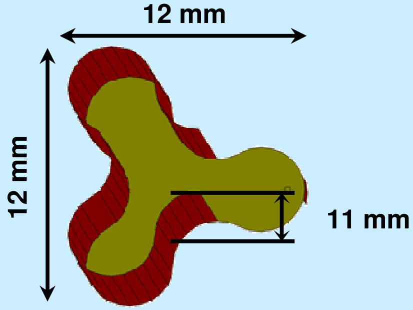
Compact Microstrip Monopole Antenna

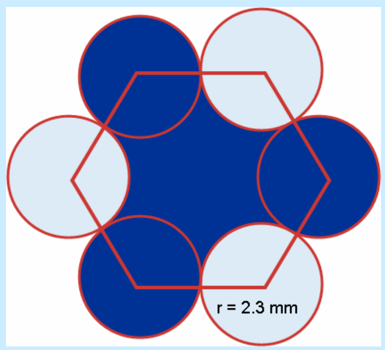
Compact Microstrip Monopole Antenna (CMMA)

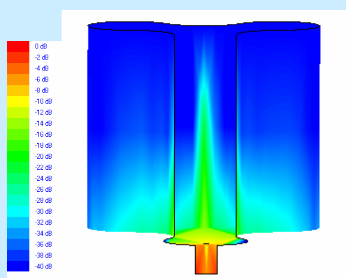
Design Concept:

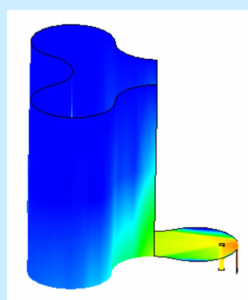
- Reduce operating frequency of patch antenna through use of grounding wall and increased perimeter with a compact footprint.
- Adjust for inherent decrease in directivity with vertical wall.
- Combine a microstrip patch with a 3-dimensional structure to attain a highly directive, broadband, compact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

$< \lambda/12$!





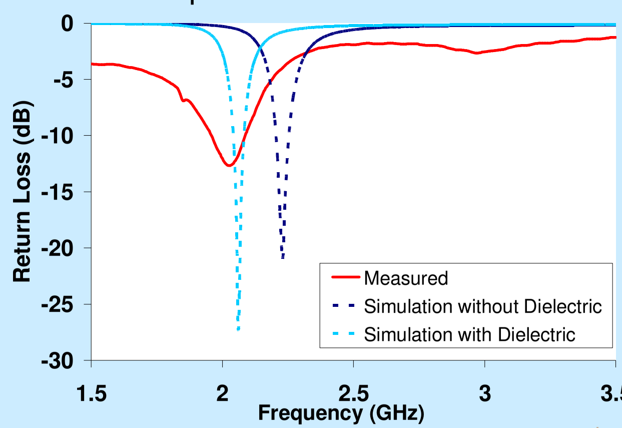


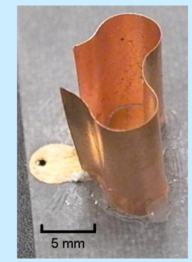


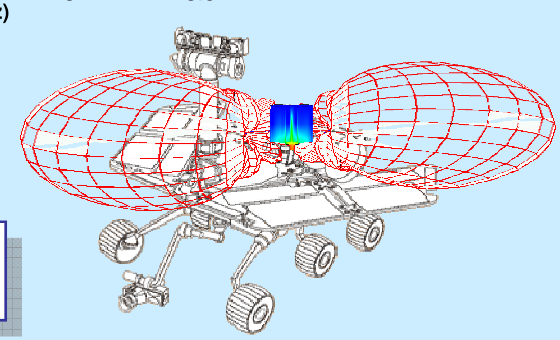
[2] Philip Barr, Afroz Zaman, Félix Miranda, "A Compact, Broadband Antenna for Planetary Surface-to-Surface Wireless Communications," Microwave and Optical Technology Letters, Vol. 48, Iss. 3, March 2006, pg. 521-524

Results:

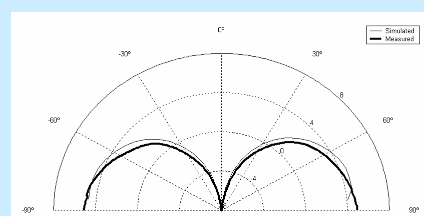
- End-fire radiation pattern allows for lunar surface-to-surface communications with an antenna structure 1/6th the size of a monopole antenna.



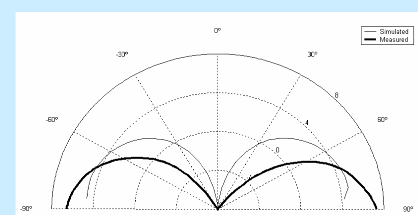




$TRL_{in} = 2$
$TRL_{out} = 3$

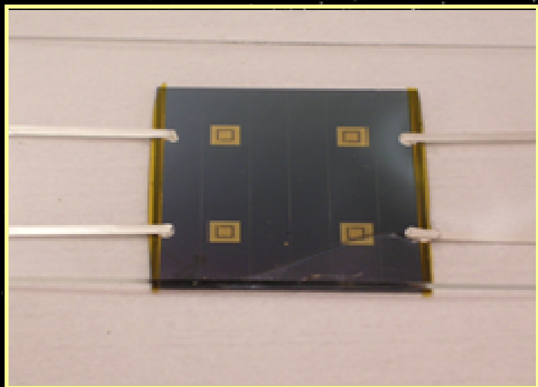


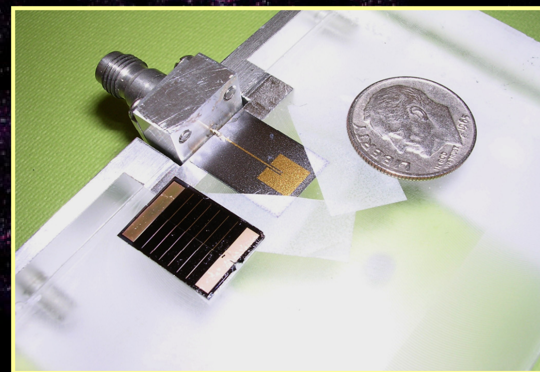
E-Plane



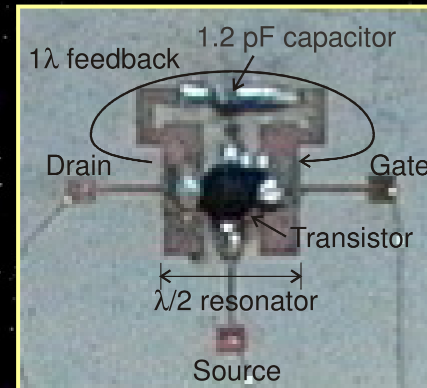
H-Plane

Self-Powered Antennas
(X-band: TRL 3)



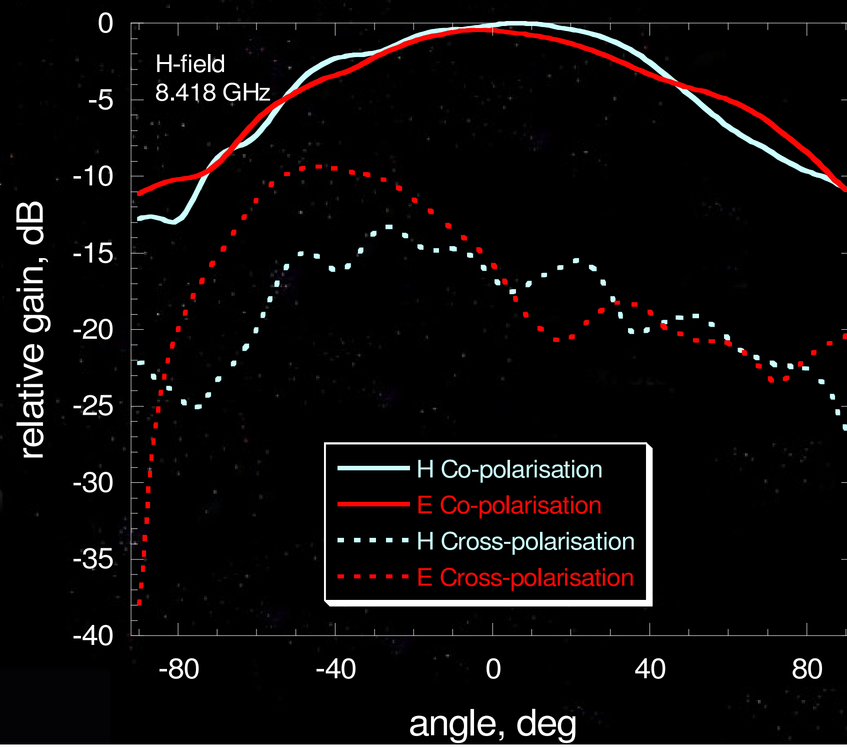


X-band Integrated antenna/solar cell



Local Oscillator

- Integration of solar cell and local oscillator with antenna provides self-powering communications system package

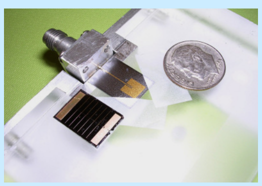


Potential Applications
- Distributed sensors/probes
- Robotic rovers
- Astronaut EVA

Solar Cell Integrated Antennas

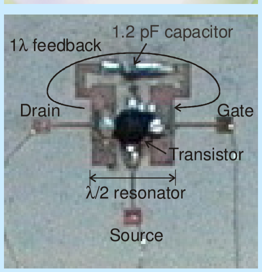
Design Concept:

- Integrate solar cell, local oscillator and miniature antenna for complete, compact, self-powering communications system.
- Integrated antenna radiating element/oscillator generates it's 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.



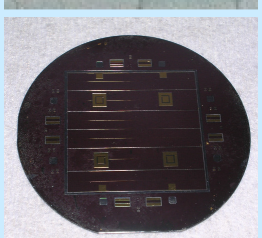
Miniature Antenna

Provides compact structure to transmit RF signal



Local Oscillator

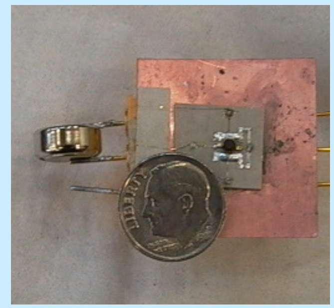
Provides modulation of frequency carrier for relevant data transmission



Solar Cell

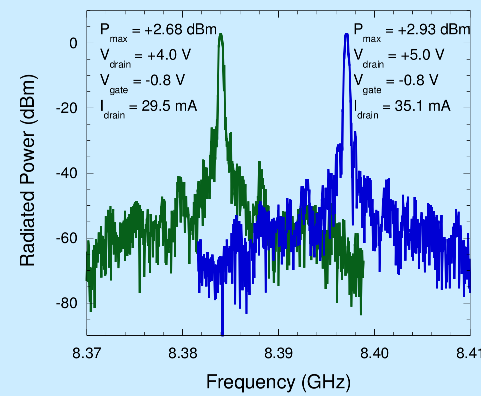
Provides power for communications system. Can be integrated on antenna layer, or on oscillator layer.

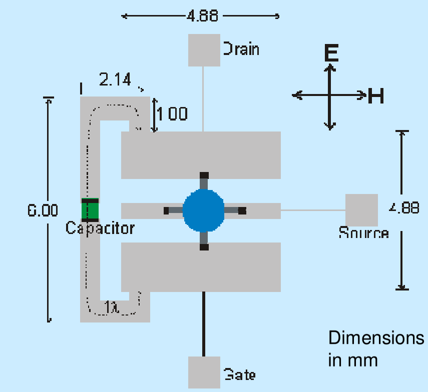
Results:

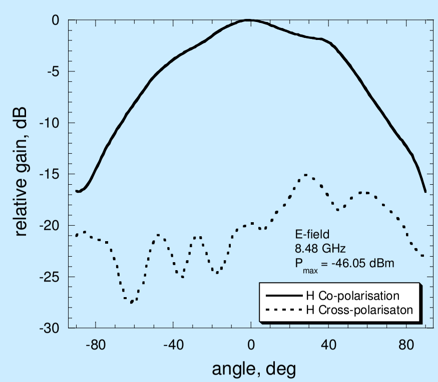


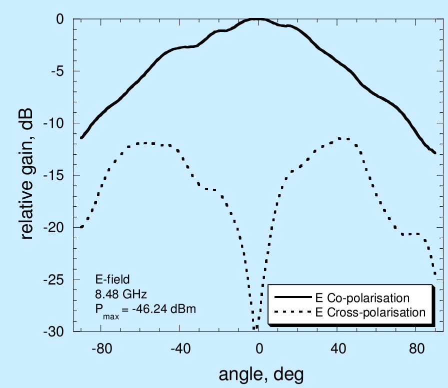
Fabricated integrated antenna/oscillator using Duroid RT 6010 microwave laminate (dielectric constant = 10.2), with pseudomorphic high electron mobility gallium arsenide transistors

$TRL_{in} = 2$
$TRL_{out} = 3$





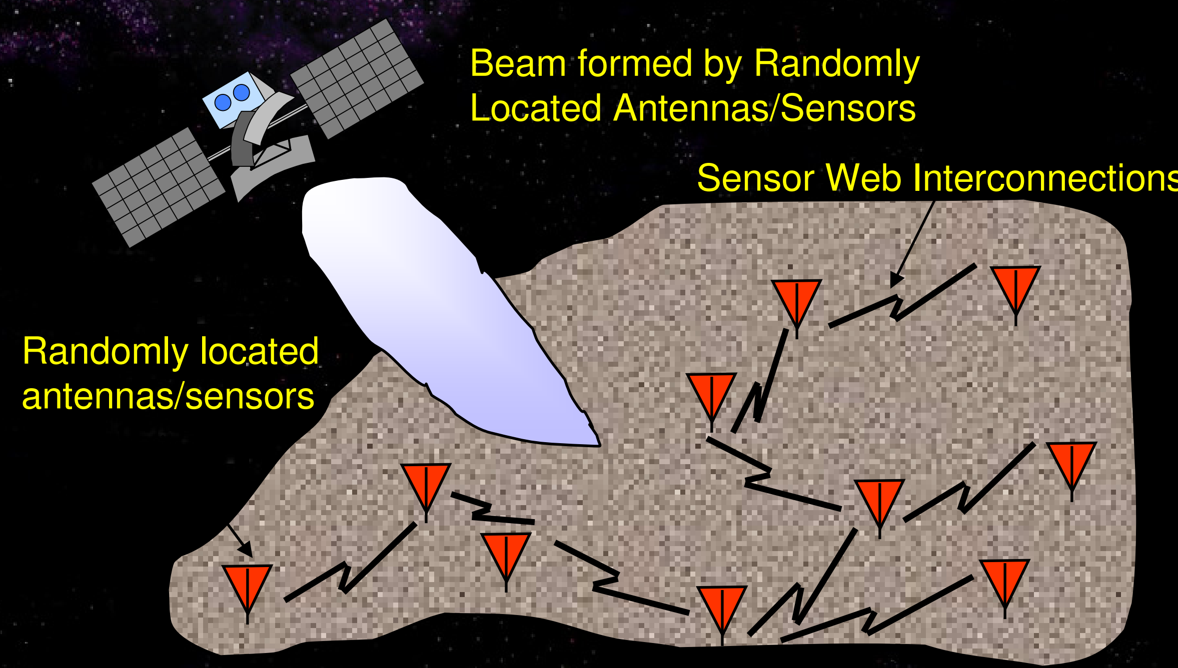




Miniaturized Reconfigurable Antenna for Planetary Surface Communications

Program Goals

- Develop electrically small (i.e., 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.
- These antennas are needed for Planetary and Moon Exploration and Monitoring Missions



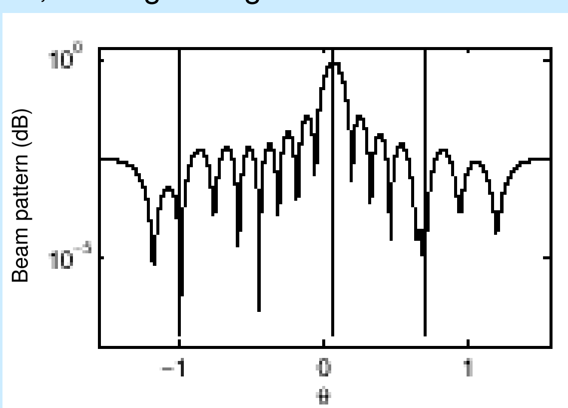
Collaboration with Dr. Jennifer Bernhard (University of Illinois)

Miniaturized Antennas in Random Sensor Arrays for Planetary Surface Exploration

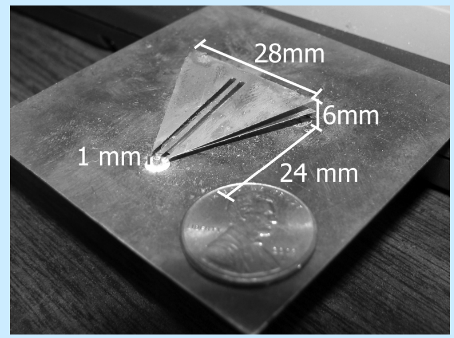
PI : Dr. Jennifer Bernhard/Univ. of Illinois

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



Simulated Beam forming Achieved Using Bayesian Estimation Method For a Random Sensor Array



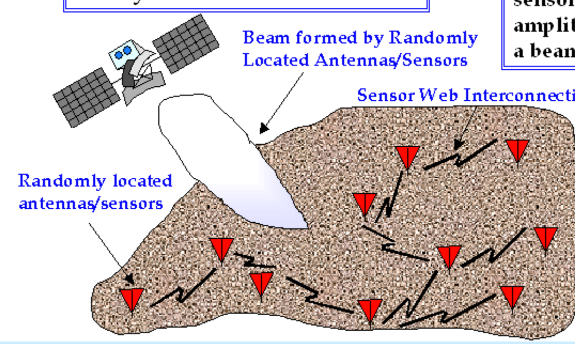
Prototype Miniaturized Antenna

TRL $_{in}$ = 2
TRL $_{out}$ = 3

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.*

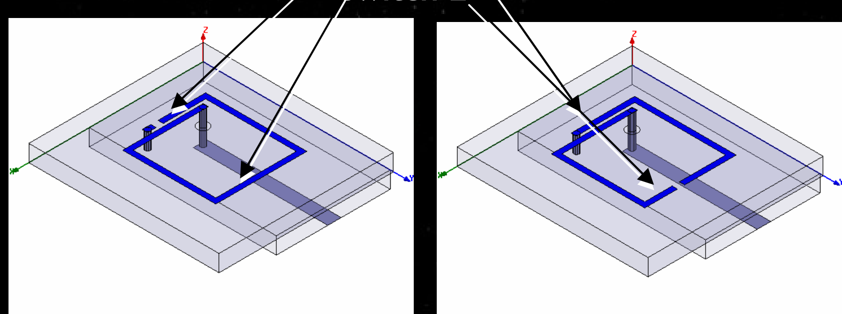


Reconfigurable Antennas for High Data Rate Multi-Beam Communication

PI: Prof. Jennifer Berhard, U. Illinois, Grant # NAG3 2555

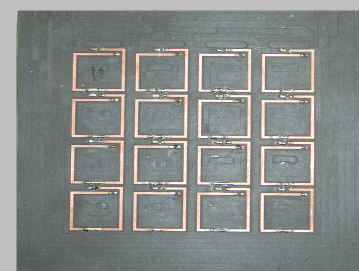
Target Technology:
Reconfigurable antenna elements capable of producing multiple beams, multiple frequencies, and array scan angles from broadside to horizon. Intended for inter-satellite, satellite-mobile and satellite-ground communication with a single array.

Antenna Elements:
Spiral microstrip patch antenna with reconfigurable switch elements activated by DC bias. Broadside to end-fire pattern reconfiguration by respective switch activation.

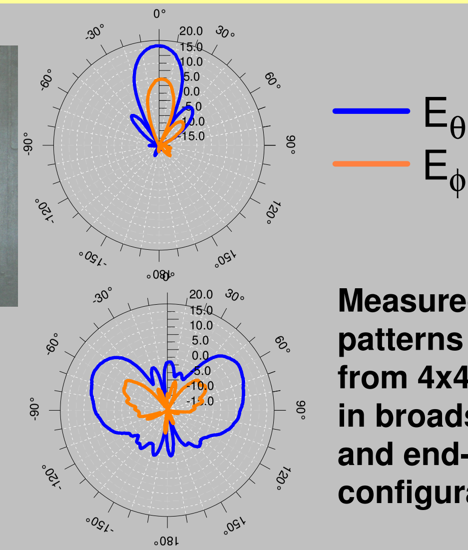


Feed through ground plane opening with via from reverse side 50Ω microstrip line

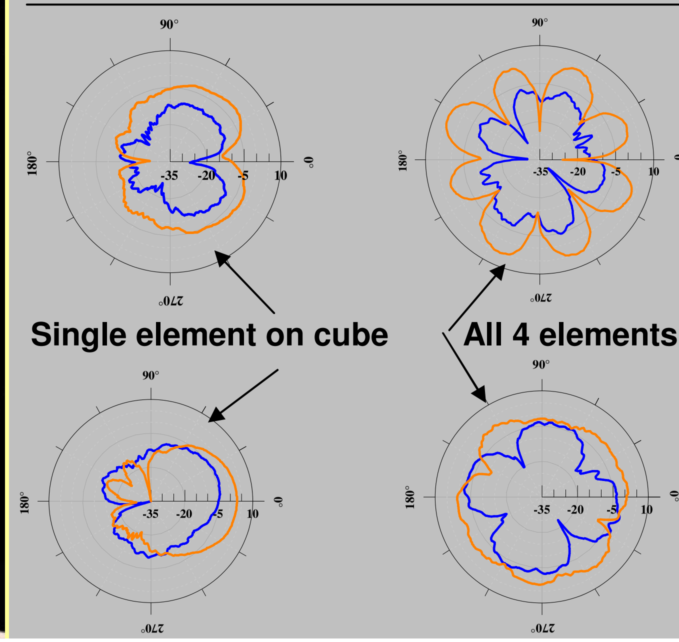
IC Compatible Prototype Square Element For monolithic MEMS integrated fabrication

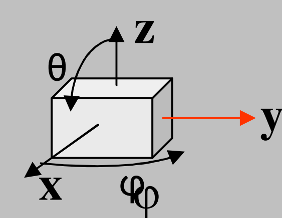


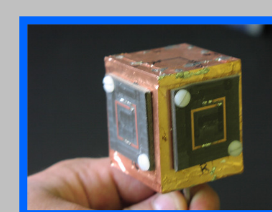
Reconfigurable antenna array (with 16 shorting wire switches)



Measured patterns (φ=0) from 4x4 array in broadside and end-fire configurations





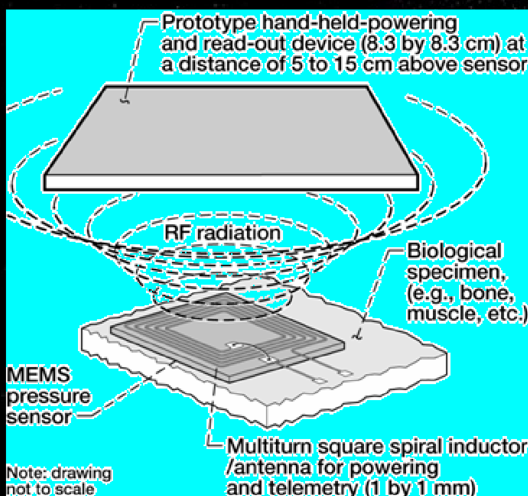


Human/Rover Application

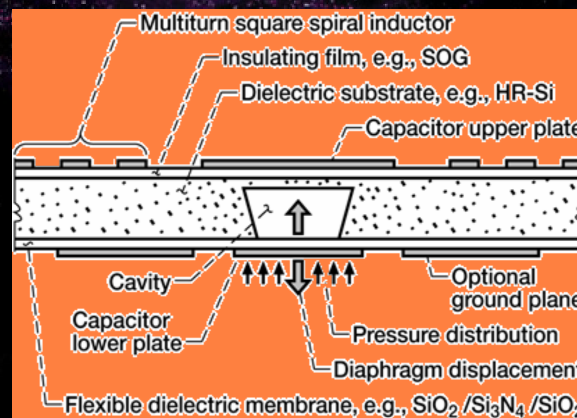
RF Telemetry System for Implantable Bio-MEMS Sensors

(TRL 3-4)

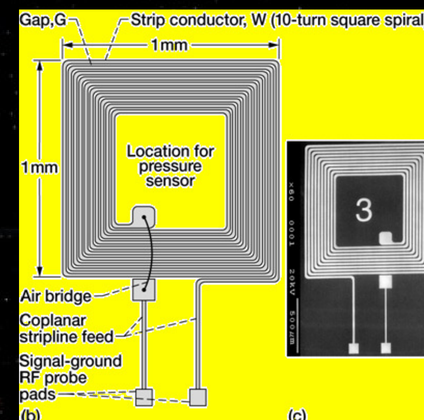
- **NASA seeks to develop telemetry based implantable sensing systems to monitor the physiological parameters of humans during space flights**
- **A novel miniature inductor and pick-up antenna for contact-less powering and RF telemetry from implantable Bio-MEMS sensors has been developed.**



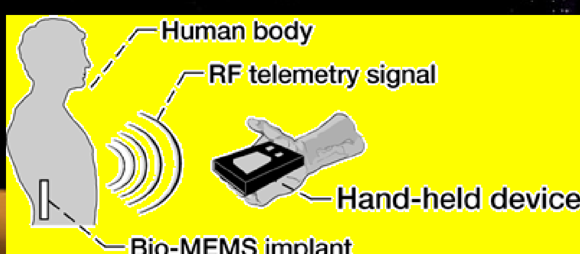
Contact-less powering and telemetry concept



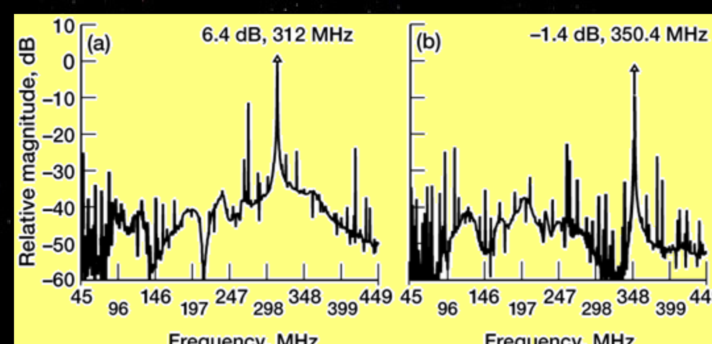
Schematic of a capacitive pressure sensor.



Schematic of miniature spiral inductor on SOG/HR-Si wafer and Photomicrograph of inductor/antenna.



Contact-less powering and telemetry application in biosensors



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

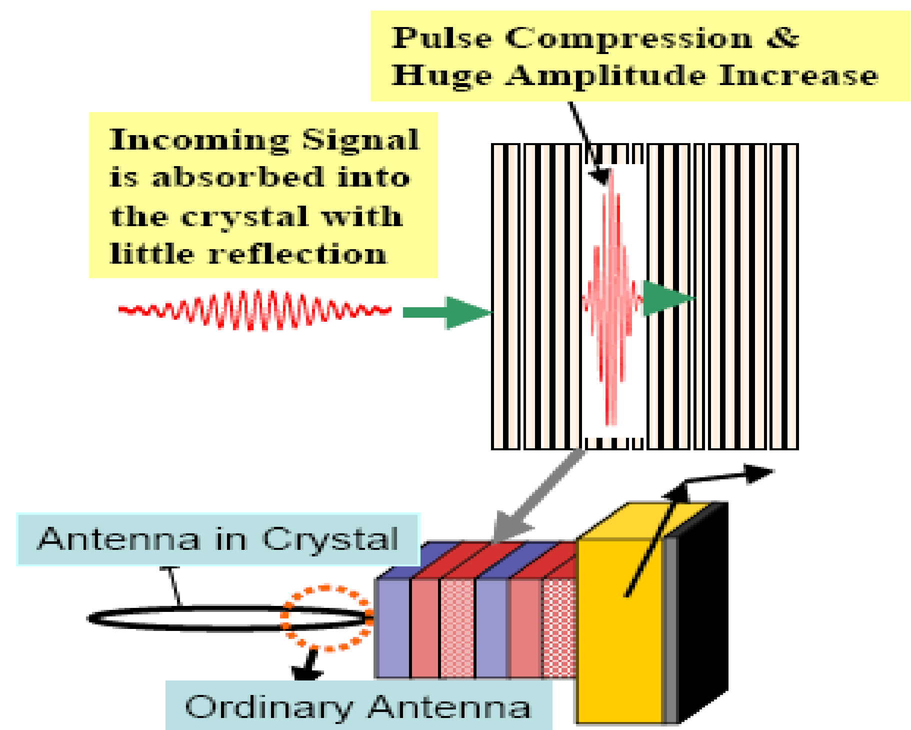


Fig. 1. MPC stack design and related benefits, including unidirectionality.

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)**