Aerospace Communications Technologies in Support of NASA Mission

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ABSTRACT

NASA is endeavoring in expanding communications capabilities to enable and enhance robotic and human exploration of space and to advance aero communications here on Earth. This presentation will discuss some of the research and technology development work being performed at the NASA Glenn Research Center in aerospace communications in support of NASA's mission. An overview of the work conducted in-house and in collaboration with academia, industry, and other government agencies (OGA) to advance radio frequency (RF) and optical communications technologies in the areas of antennas, ultra-sensitive receivers, power amplifiers, among others, will be presented. In addition, the role of these and other related RF and optical communications technologies in enabling the NASA next generation aerospace communications architecture will be also discussed.

The NASA John H. Glenn Research Center at Lewis Field

Outline of Presentation

- NASA Vision and Mission
- Importance of Communications
- Existing and Proposed Communications Networks
- Communications Technologies
- Communications Technology Development at Glenn Research Center
- Summary

NASA's Vision

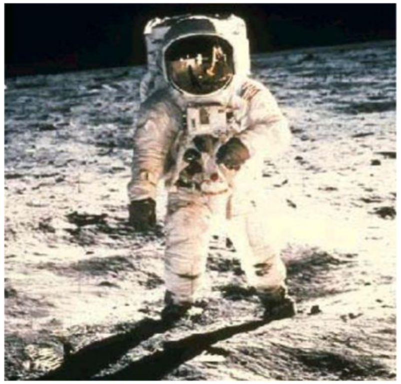
We reach for new heights and reveal the unknown for the benefit of humankind.

http://www.nasa.gov/about/index.html

NASA Mission

To Pioneer the Future in Space Exploration, Scientific Discovery, and Aeronautics Research.

Importance of Communications



Robotic-based Exploration

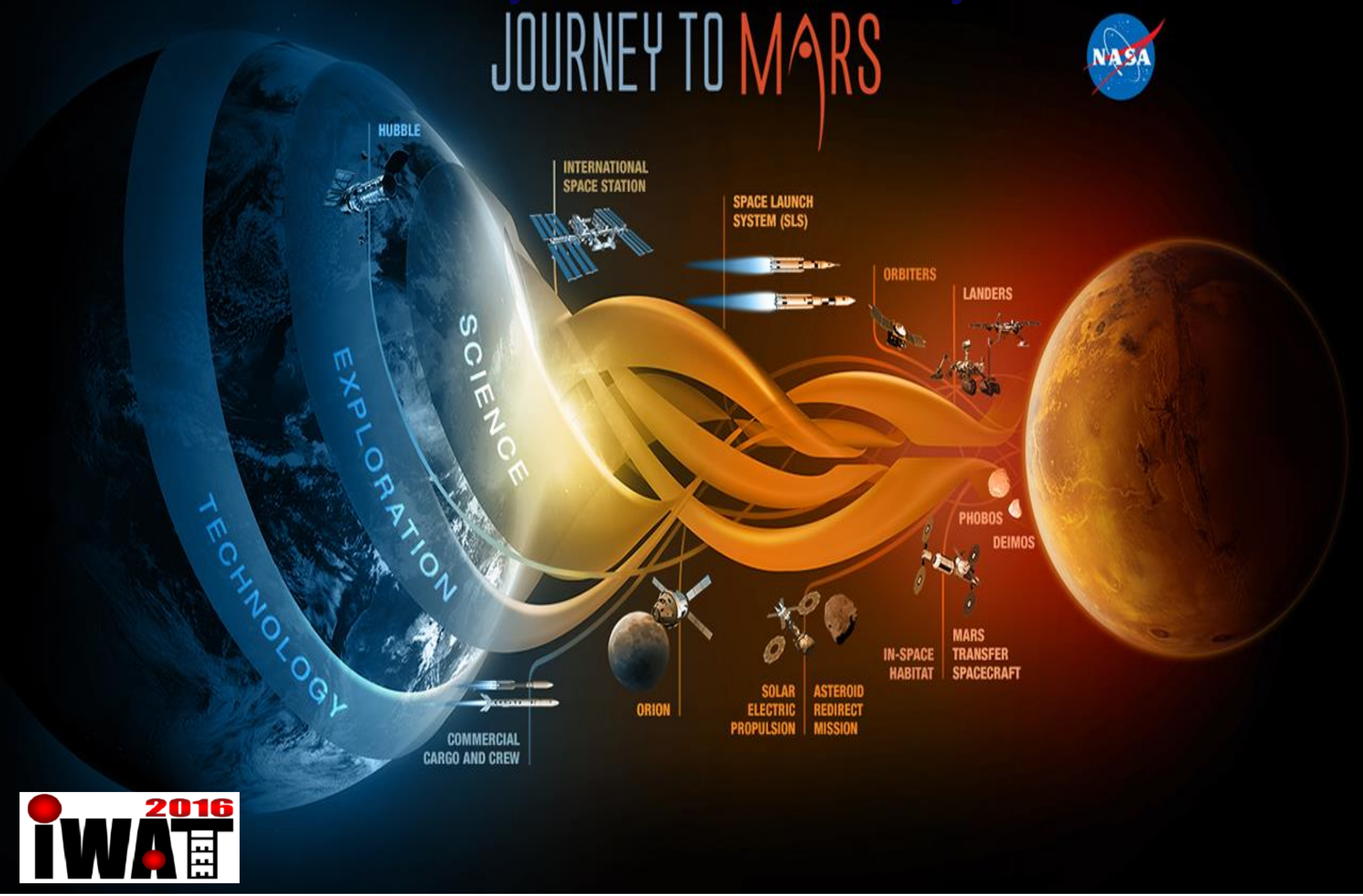
Human-based Exploration

Spacecraft/Satellite-based Exploration

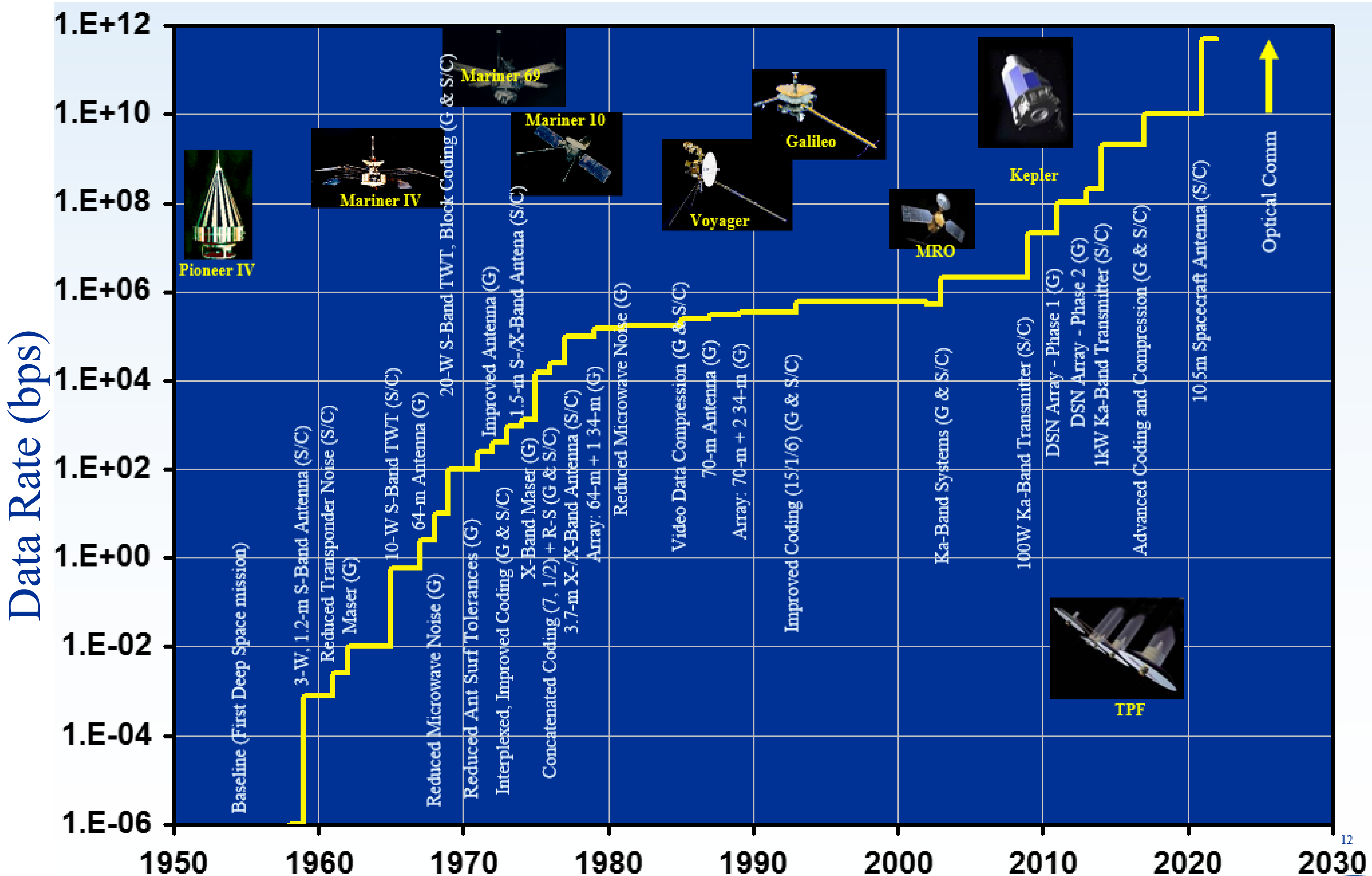
Enable Forward/Return Communications and TT&C with:

- Humans in the space environment
- Spacecraft
- Planetary Surface (e.g., Rovers)
- Aircraft and other airborne platforms

Journey to Mars…and Beyond



Increase of Date Rate as a function of Time



Existing and Proposed Communications Networks

Space Communications and Navigation (SCaN) Operational Network

Communications System Drivers

Driving Requirements

- Provide space communications and navigation services to existing and planned missions. (2010–2025+)
- Develop a unified space communications and navigation network infrastructure
- Implement internationally interoperable communication protocols
- Provide the highest data rates technically and financially feasible
- Implement a networked communication and navigation infrastructure across space
- Provide communiation and navigation infrastructure and services for Lunar and Mars human missions

Mission Drivers

2010

- Shuttle/ISS
- Mars Landers
- Great Observatories
- Coordinated Earth Observation
- LRO


2015

- ISS
- Mars – Coordinated and Complex Science Missions
- SAR Earth Observation
- Curiosity rover


2020

- ISS
- MPCV/Orion
- SLS
- Asteroid Sample Return
- High Data Volume Hyper Spectral Missions

2025+

- Hyper spectral imaging at Mars and beyond
- Human Near Earth Object Missions
- Earth Sensor Web
- Mars Exploration
- Mars Sample Return

Capabilities

2010

- Up to 300 Mps (EBRE/NEE)
- Up to 6 Mbps at 1 AU (DSE)
- Radiometric Services

2015

- Up to 1.2 Gbps (EBRE)
- Up to 13 Mbps at 1 AU (DSE)
- Standard Services
- Integrated Mission Commitment
- Radiometric Enhancements

2020

- Up to 50 Mbps at 1 AU
- Integrated Network Management
- Integrated Service Execution
- Space Internetworking

2025+

- Up to 1.2 Gbps from the moon (optical)
- Optical Communications to 100 Mbps (planetary)
- Lunar far side coverage
- High capacity multi-node
- Inter-networking interoperability

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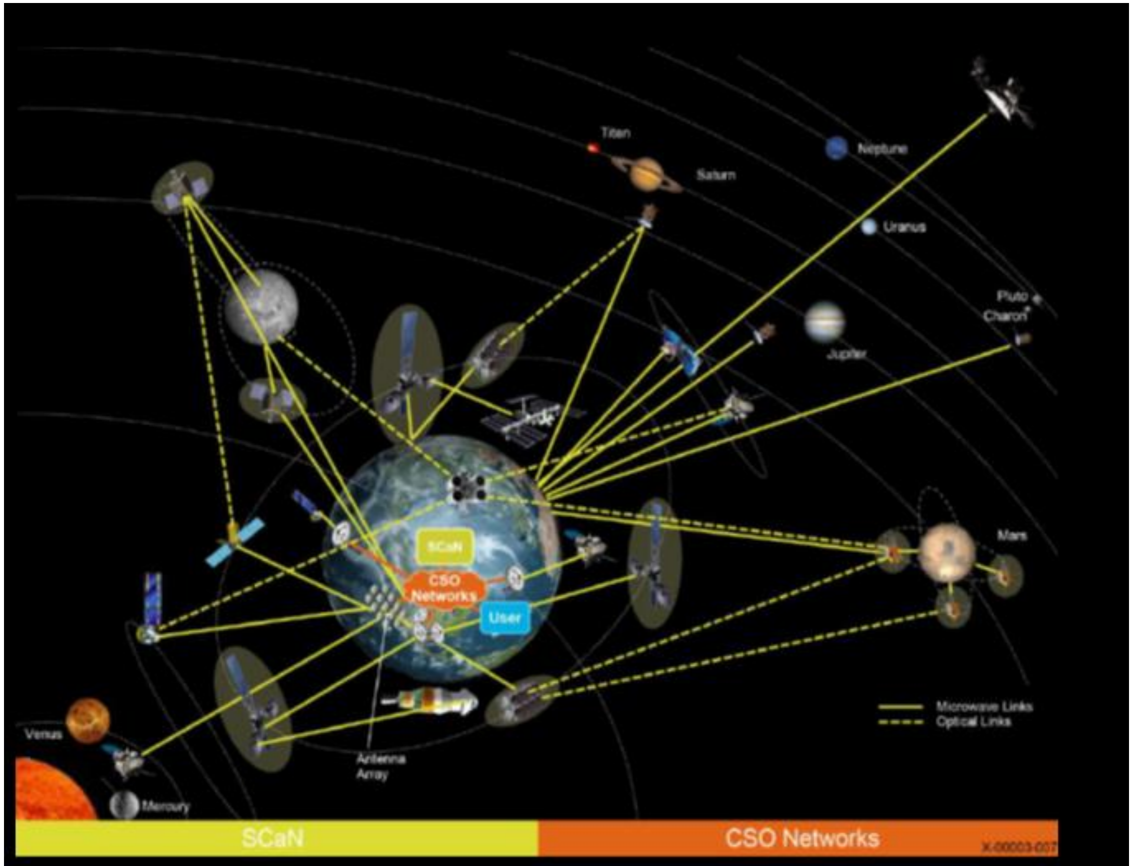
Ref: SCaN Architecture Definition Document

Top Level Conceptual Communication Architecture ~2025

Key Capabilities

- Solar system-wide coverage
- Anytime, anywhere connectivity for Earth, Moon, and Mars
- Integrated service-based architecture and network management
- New technologies (optical, arraying, SDRs) infused into the Space, Communications and Navigation (SCaN) Network
- International/Commercial interoperability using standard interfaces

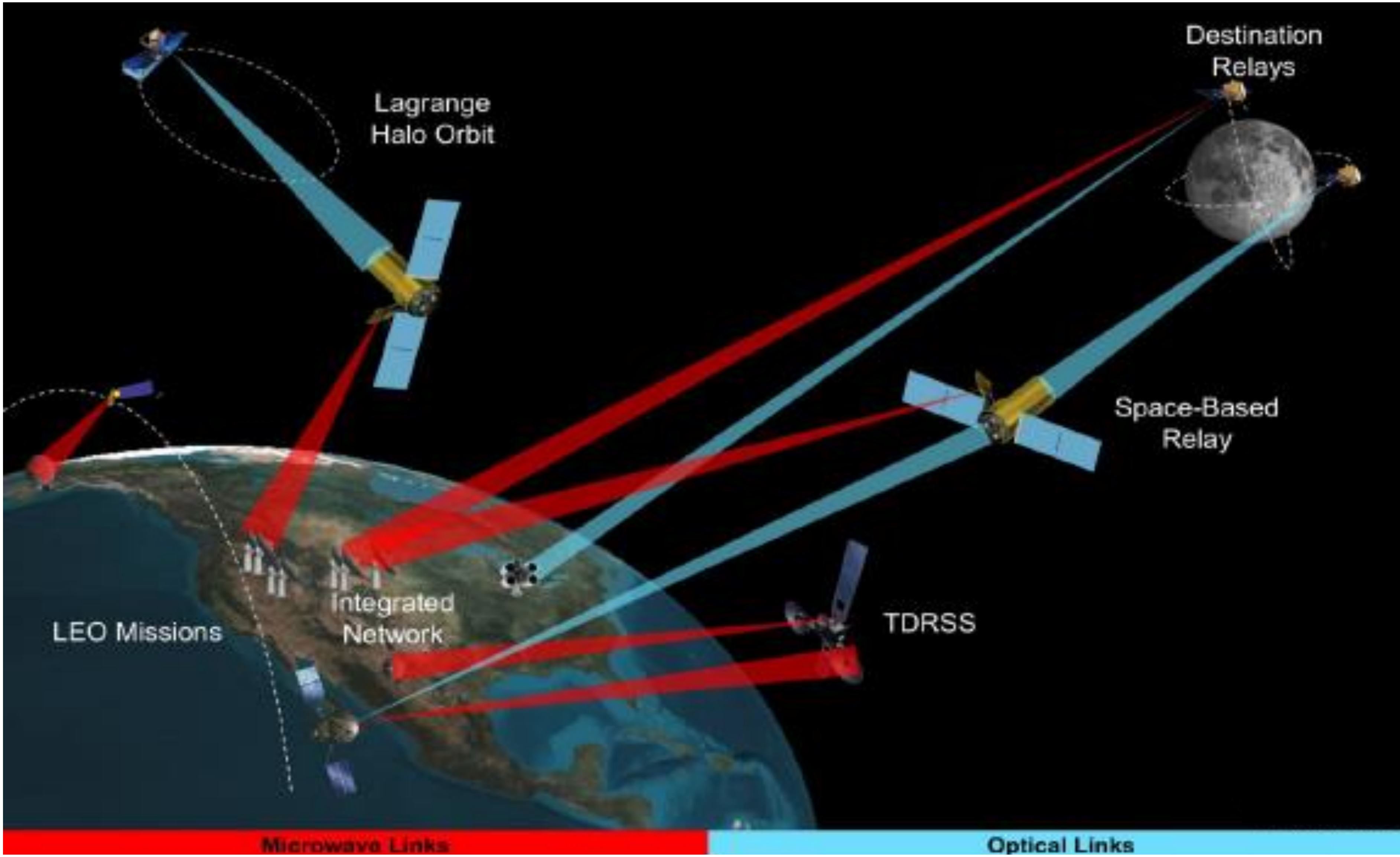
Consists of highly reliable low to high rate microwave links augmented with very high data rate optical links for both direct-to-Earth and relay communications



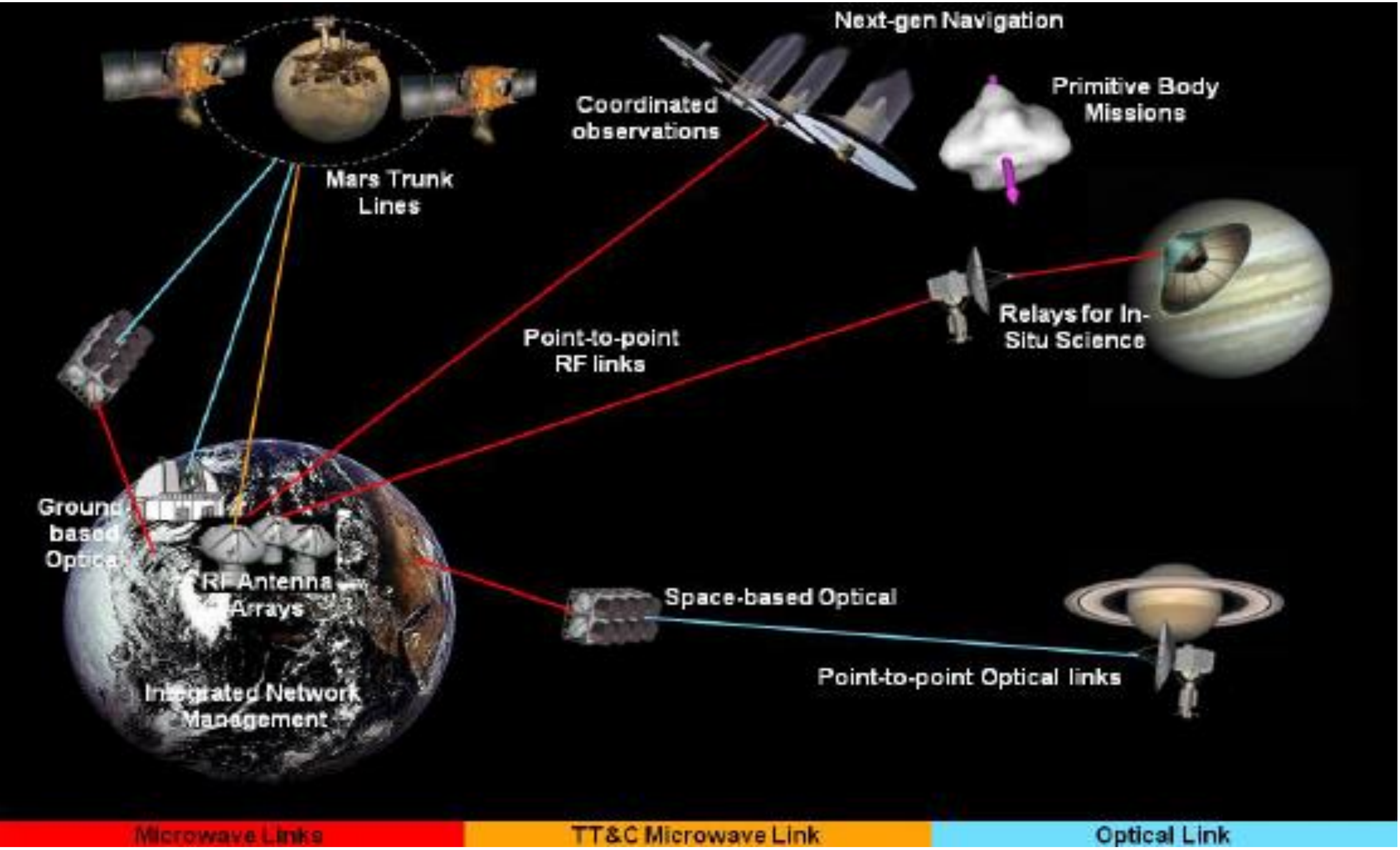
Phase 3 – Integrated NASA Networks

Phase 3 is the final completed version of the Integrated NASA Network.
CSO—Communications Service Office (Ground Network)

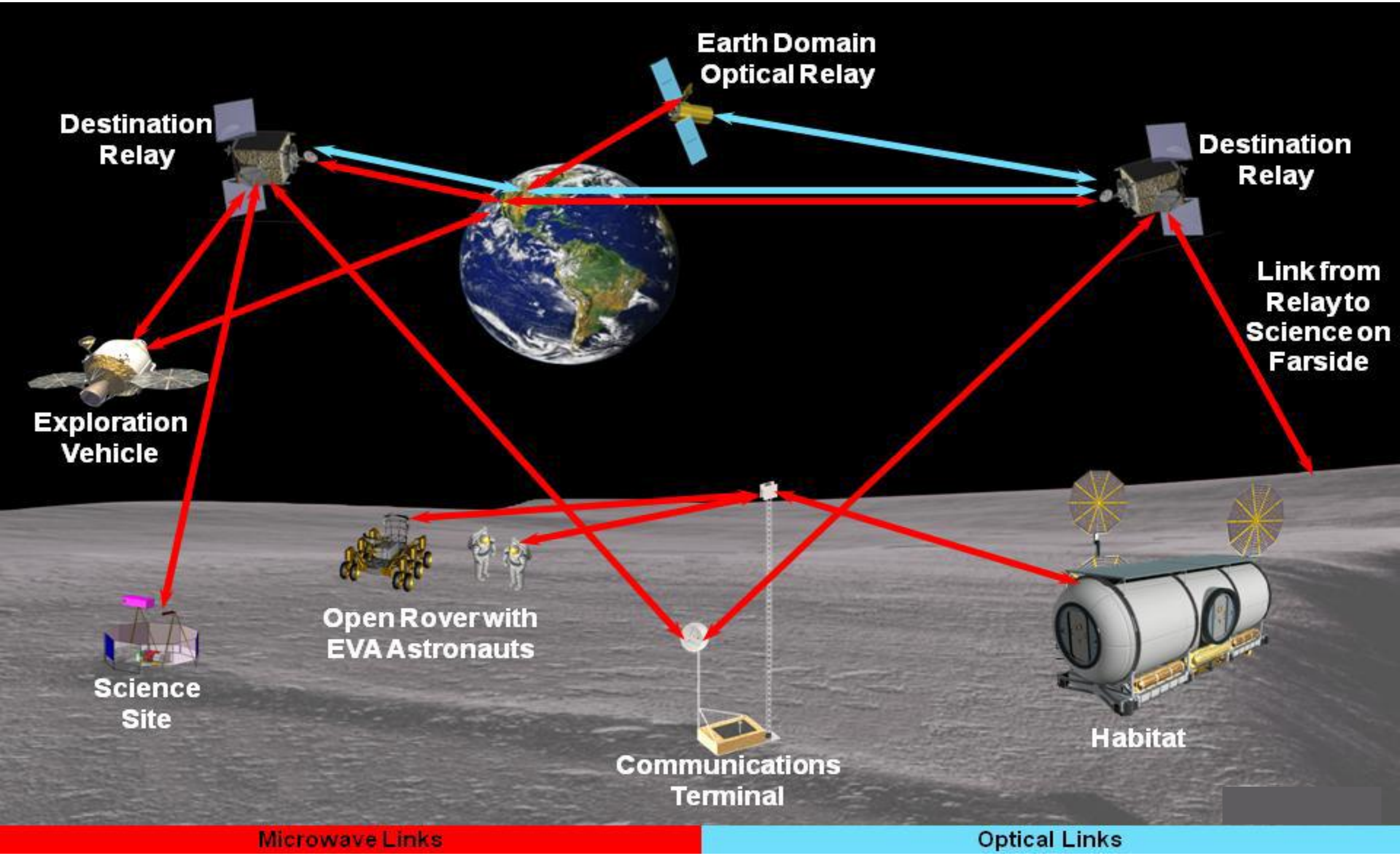
Near Earth Network



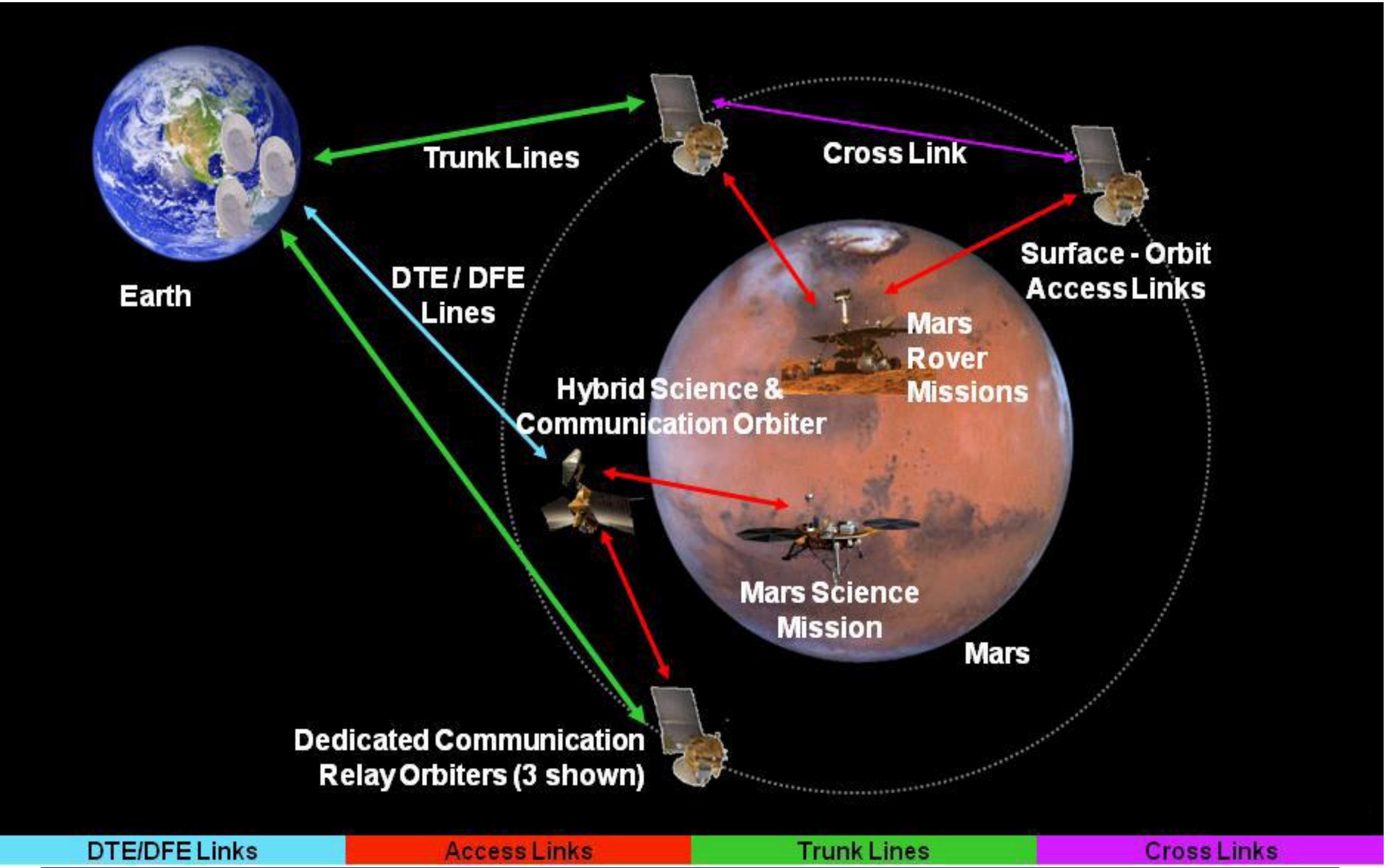
Deep Space Network



Lunar/Near Earth Object Relay Architecture



Mars Relay Architecture



Conceptual Architectures

	NEN	DSN	Lunar/NEO Relay	Mars Relay
Performance Requirements	➢Near Earth Optical initial operational capability to provide ***minimum 1.2 Gbps (return)/100 Mbps (forward) links*** in 2022 timeframe. ➢RF link enhancements will provide minimum ***150 Mbps to L2 and 1.2 Gbps to LEO/MEO orbits at Ka-band (return) and 25 – 70 Mbps from LEO to moon at Ka-band (forward)***	➢***Develop use of Ka-band*** for high data rate return from deep space ➢***RF antenna arrays at X-band*** for robust emergency communications ➢***Deep Space Optical*** initial operational capability to provide minimum of 100 Mbps (return) at 1 AU, extendable to multi-Gbps, and minimum 2 Mbps (forward)	➢Emerging communications and navigation relay requirements to address Lunar and Near Earth Object (NEO) rendezvous missions whose primary drive is high data rate return ➢High rate forward and return links scalable to address varying coverage requirements ➢Simultaneous communications to multiple orbiting and surface elements ➢High rate forward and return links via RF and optical	➢Scalable to support evolving Mars mission requirements ➢***150 Mbps (return) links*** via more powerful transmitters and antenna arrays at Ka-band. ➢***Optical trunk link to Earth at 600 Mbps (return)*** ➢***Simultaneous communications to multiple orbiting and surface elements via space internetworking protocols (e.g., multi-beam antennas)***
Mission Examples	➢*Soil Moisture Active Passive (SMAP)* ➢*James Webb Space Telescope (JWST)* ➢*Wide Field Infrared Survey Telescope (WFIRST)* ➢*Synthetic Aperture Radar (SAR)* ➢*Human exploration which require robust, high rate return links and near continuous tracking coverage*	➢Mars Sample Return ➢Mars Atmosphere and Volatile Evolution (MAVEN) ➢Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) ➢New Frontiers and outer planetary missions which require extreme distance links and emergency TT&C capabilities	➢Asteroid Redirect Mission	➢Mars support missions include Mars Science Laboratory (MSL), MAVEN, InSight, NASA partner missions, and eventual human exploration

To enable these Communications Networks we need Communications Technologies

National Aeronautics and Space Administration

SCaN Technology Development Roadmap

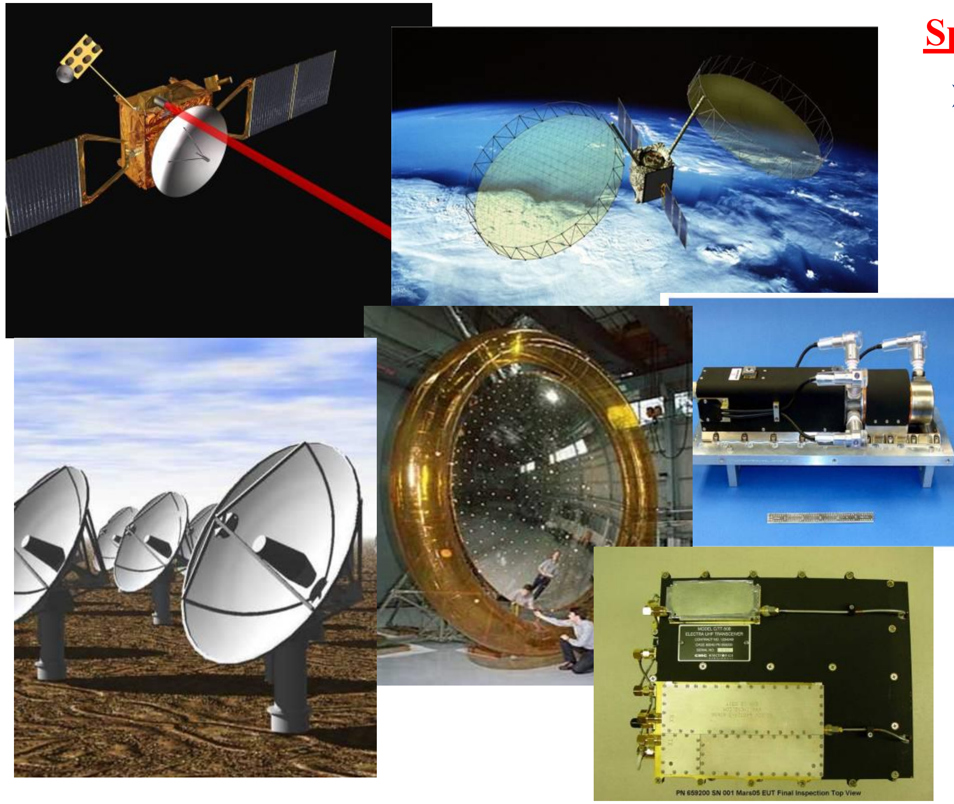
Enabling Technologies for Space Communications

Optical Communications

- High capacity comm with low mass/power required
- Significantly increase data rates for deep space
- LLCD (October 2013; 622 Mbps Moon to Earth Surface)*
- Other efforts (LCRD, DSOC, iROC being developed)

Uplink Arraying

- Reduce reliance on large antennas and high operating costs, single point of failure
- Scalable, evolvable, flexible scheduling
- Enables greater data-rates or greater effective distance



Spacecraft RF Technology

- High power sources, large antennas and using surface receive array can get data rates to hundreds of Mbps from Mars

Software Defined Radio/Cognitive Systems

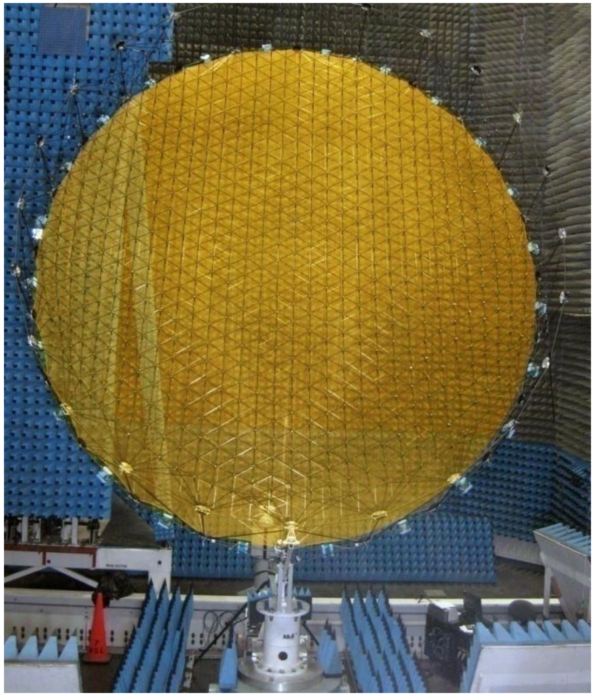
- Reconfigurable, flexible, interoperable allows for in-flight updates open architecture.
- Reduce mass, power, vol.

* http://llcd.gsfc.nasa.gov

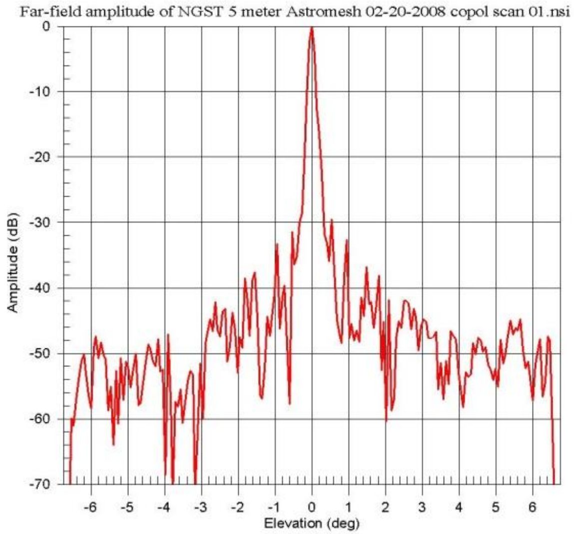
Some Examples of Technologies Relevant to Space Communications

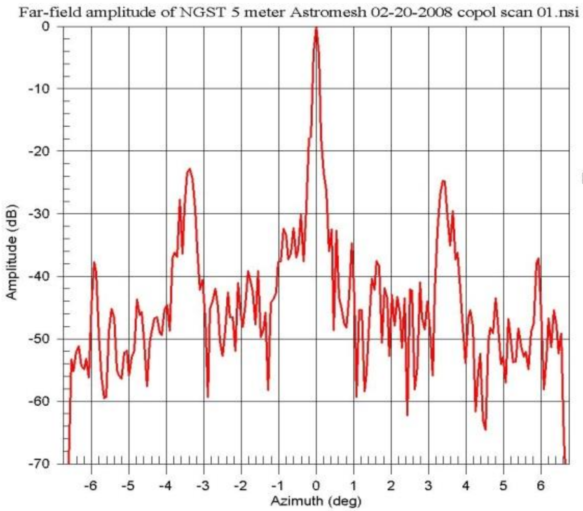
Large Aperture Deployable Antennas

Mesh Reflectors

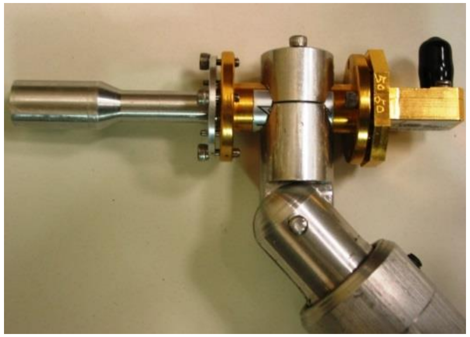


NGST 5 m “Astromesh” Reflector in NASA GRC Near-Field Range. The reflector was evaluated at 32, 38, and 49 GHz as well as a laser radar surface accuracy mapping.





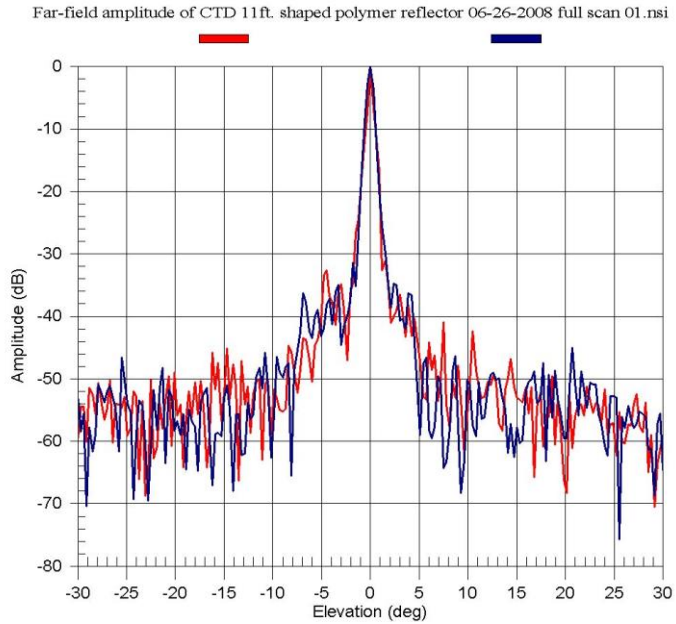
Far Field Elevation and Azimuth pattern at 33 GHz (Directivity = 62.8 dB)



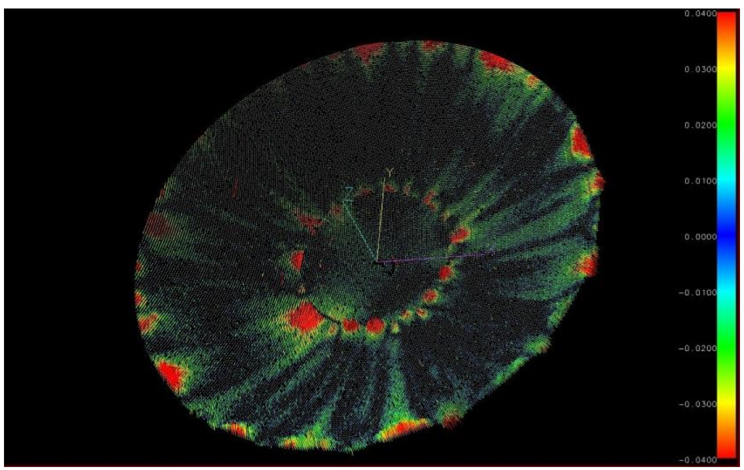
GRC Dual-band feed horn assembly

Shape Memory Polymer Reflector

Composite Technology Development 3.2 m Shape Memory Polymer Composite Reflector at GRC Near Field

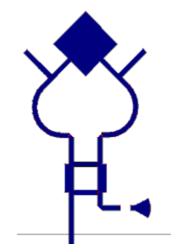


Far-field pattern at 20 GHz. Directivity = 50.3 dB (aperture was severely under-illuminated)



Surface metrology based on laser radar scan. RMS error=0.014"

Stowed Configuration



Initial 20 GHz Microstrip Patch Feed (length is 0.620")

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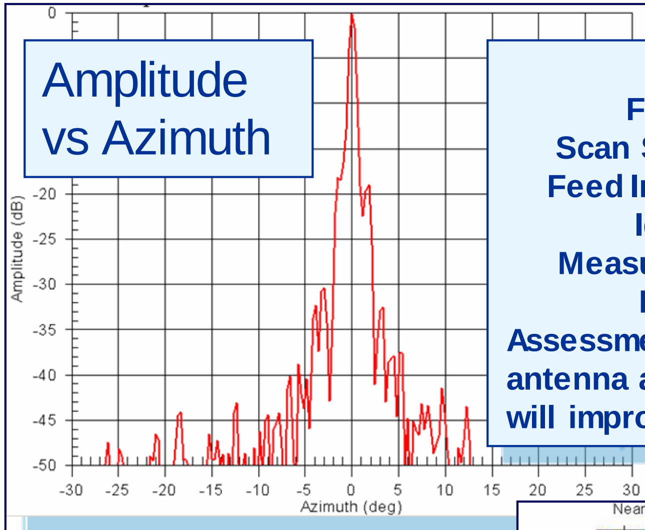
Large Aperture Inflatable Antennas

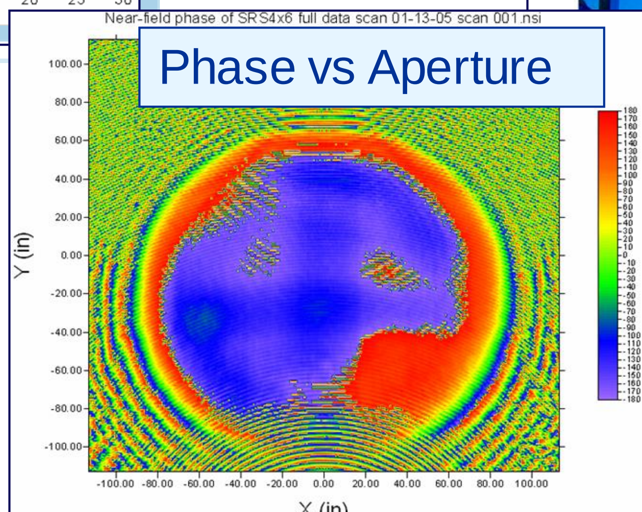


Amplitude vs Azimuth

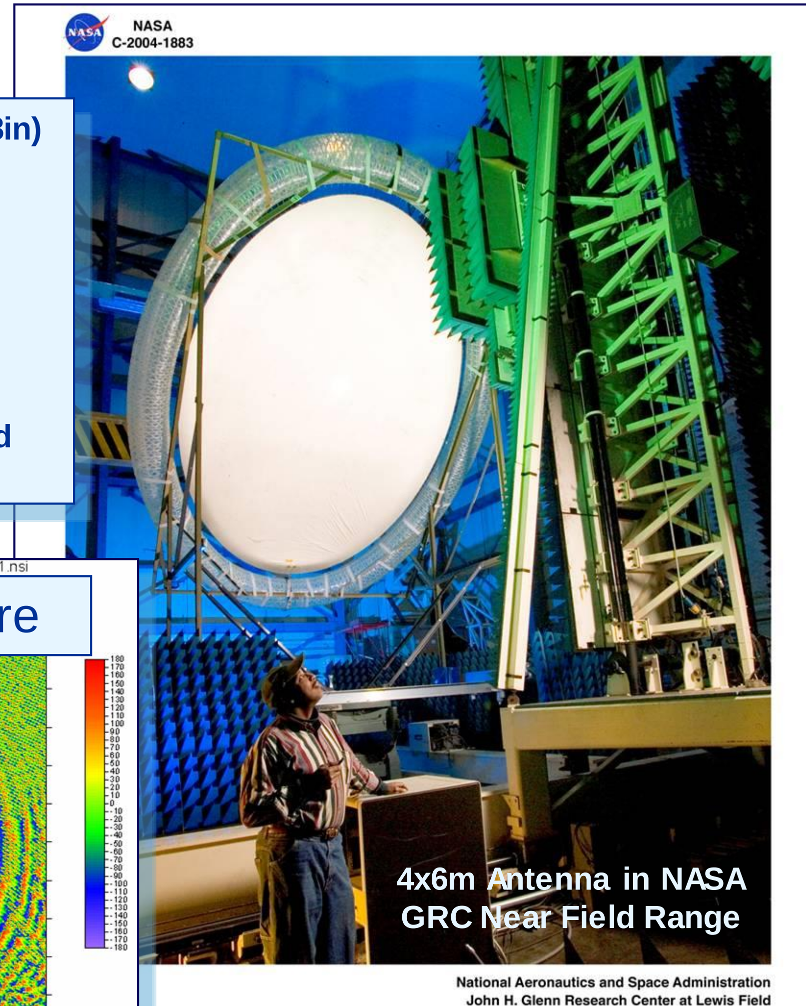
Aperture: 4.17m (164.08in)
Frequency: 8.4GHz
Scan Step Size: $\lambda/2$
Feed Inclination: 5°
Ideal Gain: 51.3dB
Measured Gain: 49.3dB
Efficiency: 63.33%

Assessment: Performs well as antenna at X-band. Optimized feed will improve performance.

Design Specs
- 4x6m off-axis parabolic antenna
- Inflatable
- CP-1 Polymer
- RF coating
- Rigidized support torus
- Characterized in NASA GRC Near Field Range



Phase vs Aperture



4x6m Antenna in NASA GRC Near Field Range

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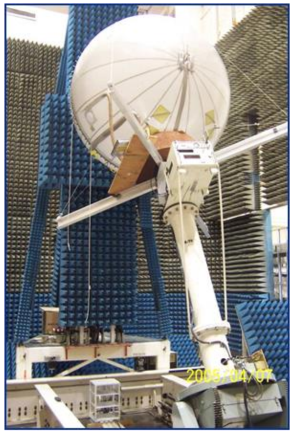
Large Aperture Deployable Antennas



Prototype Inflatable Radome Antenna System at GRC

GPS GND Terminals: 2014

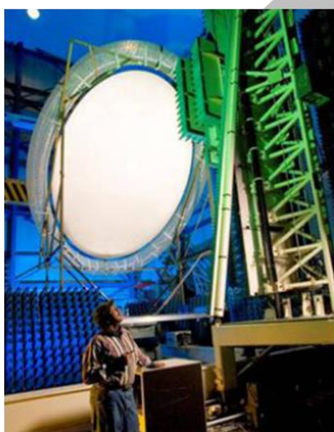
In The Field: 2009-2010

Popular Science's – Invention of the Year 2007, listed as one of the "Inc. 500: The Hottest Products" of 2009. GATR continues to field units which enable high-bandwidth Internet, phone and data access for deployments and projects in Afghanistan, South Africa, South America, Haiti, Korea, as well as assisting hurricane disaster recovery here on our own soil.

2011 2011 2010 2013

First Practical System: 2008

Through the help of NASA Glenn, the SCAN project, a reimbursable Space Act Agreement, material refinements through Air Force Research Laboratory (AFRL) and the Space and Missile Defense Command (SMDC), GATR Technologies markets World's first FCC certified inflatable antenna



4m x 6m parabolic membrane reflector derived from solar concentrator in GRC near-field

Fundamental Research: 2004-2007

Designed and fabricated a 4x6m off-axis inflatable thin film antenna with a rigidized support torus. Characterized the antenna in the NASA GRC Near Field Range at X-band and Ka-band. Antenna exhibited excellent performance at X-band. Ka-band surface errors are understood.

0.3 meter prototype Membrane reflector

Seedling Idea: 2004

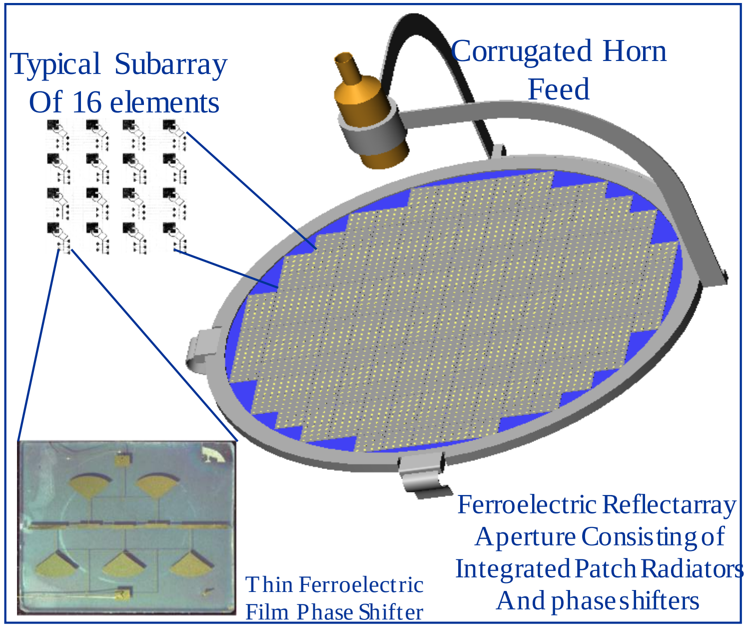
Circa 2004 need for large aperture deployable antenna identified for JIMO and Mars Areostationary relay platform. Antenna technology adapted from 1998 Phase II SBIR solar concentrator project.

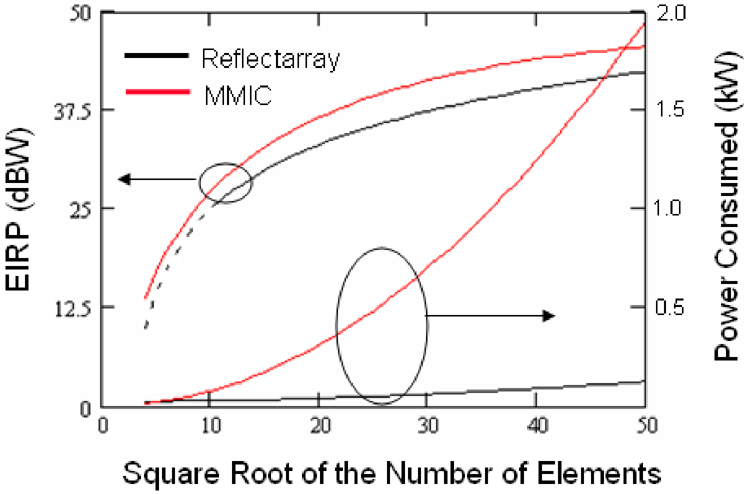
Reflectarray Array Antenna

Low Cost, High Efficiency Ferroelectric Reflectarray

Technology Description:

- Alternative to gimbaled parabolic reflector, offset fed reflector, or GaAs MMIC phased array
- Vibration-free wide angle beam steering (>±30°)
- High EIRP due to quasi-optical beam forming, no manifold loss
- Efficiency (>25%) intermediate between reflector and MMIC direct radiating array, cost about 10X lower than MMIC array.
- TRL at demonstration: 4





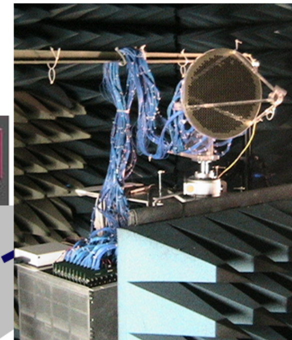
Ferroelectric Reflectarray Antenna—The Road from Idea To Deployment

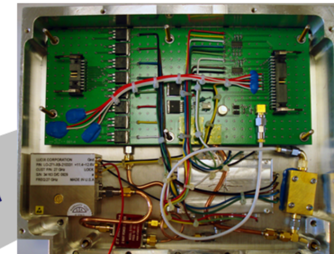
Modified 615 Element Scanning Ferroelectric Reflectarray: 2005-2009

Prototype antenna with practical low-power controller assembled and installed in NASA GRC far-field range for testing. Low-cost, high-efficiency alternative to conventional phased arrays

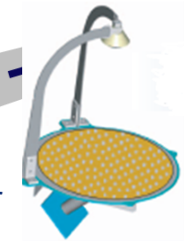
R&D 100 Award Winner

2010



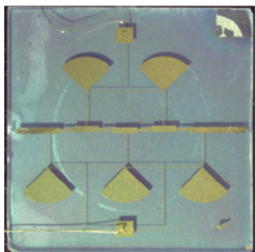


MISSE-8 ISS Space Exp.; STS-134 ,05/16/ 2011. Returned to Earth 07/2014



Cellular Reflectarray: 2010

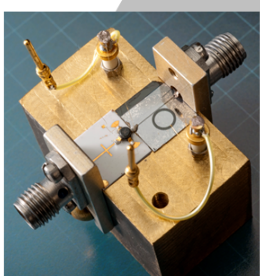
Derivative attracts attention for commercial next generation DirecTV, etc. applications



Thin film ferroelectric phase shifter on Magnesium Oxide

Practical Phase Shifters : 2003-2004

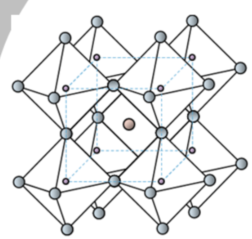
Novel phased array concept based on quasi-optical feed and low-loss ferroelectric phase shifters refined. 50 wafers of $Ba_{0.5}Sr_{0.5}TiO_3$ on lanthanum aluminate processed to yield over 1000 ferroelectric K-band phase shifters. Radiation tests show devices inherently rad hard in addition to other advantages over GaAs



First Ku-Band tunable Oscillator based on thin ferroelectric films

Fundamental Research: 2000-2003

Agile microwave circuits are developed [using room temperature Barium Strontium Titanate ($Ba_{0.5}Sr_{0.5}TiO_3$)], including oscillators, filters, antenna elements, etc., that rival or even outperform their semiconductor counterparts at frequencies up to Ka-band



Parent crystal: Strontium Titanate

Seedling Idea: 1995-1999

Basic experiments with strontium titanate at cryogenic temperatures suggest loss tangent of ferroelectric films may be manageable for microwave applications

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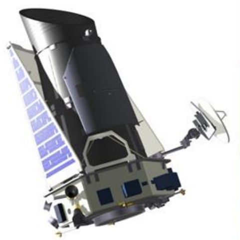
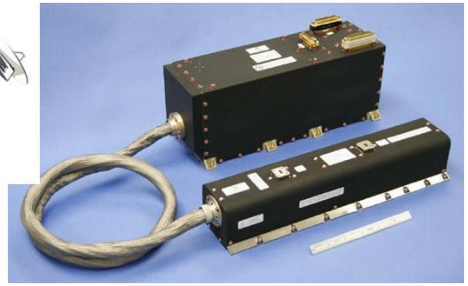
Power Amplifiers

High Power & Efficiency Space Traveling-Wave Tube Amplifiers (TWTAs) - A Huge Agency Success Story





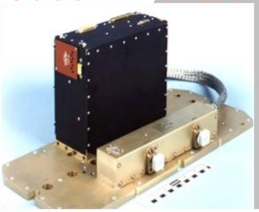
LRO TWTA

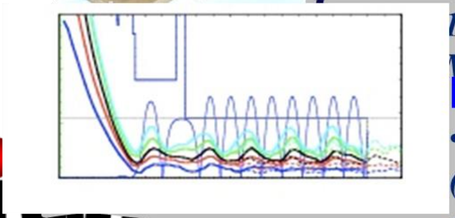
SCaN Testbed TWTA

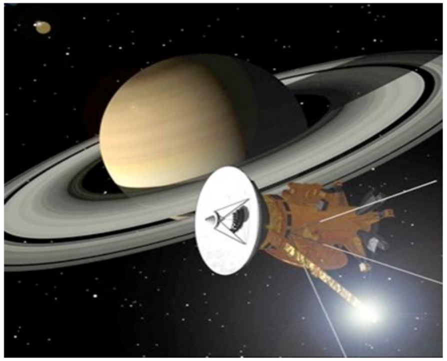
High Throughput

100 Watt TWT

Cassini TWTA







Q - V- & W-band TWTAs & Gbps Data Rates: 2012 & beyond

Lunar & ISS Missions: 2007-2011

- *Delivered K-band 40 W space TWTAs to the Lunar Reconnaissance Orbiter & CoNNeCT missions*

Jupiter Mission – Higher FoM: 2004-2006

- *Space qualified a Ka-Band TWT, output power 200 W, efficiency 62 %, mass 1.5 kg. Output power 20X higher than Cassini TWT and FoM is 133*

Mars Mission – Higher Power & Efficiency: 2001-2003

- *Demonstrated a Ka-Band space TWT, output power 100 W, efficiency 60 %, mass 2.3 kg. Output power 10X higher than the Cassini TWT and FoM is 43*

Cassini Mission: 1996-2000

- *Delivered a Ka-Band space TWT, output power 10 W, efficiency 41 %, mass 0.750 kg. Figure of Merit (FoM) is power/mass = 13*

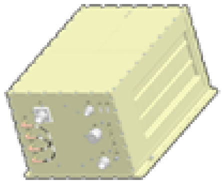
Modeling & Simulations: 1980-1995

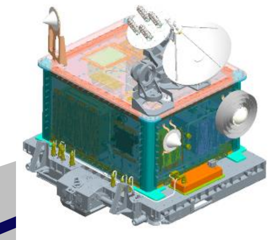
- *Basic design studies on traveling-wave tube (TWT) slow wave interaction circuits, collector circuit, focusing structure, electron gun and cathode*

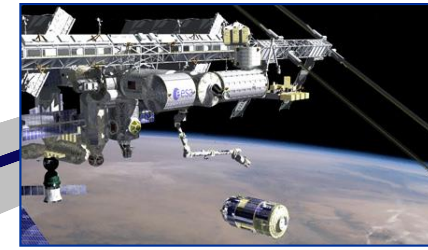
Software Defined Radios-STRS Architectures

Software Defined Radios-STRS Architectures

2010 – SCaN Testbed Flight Radios Developed by General Dynamics, Harris Corp., JPL



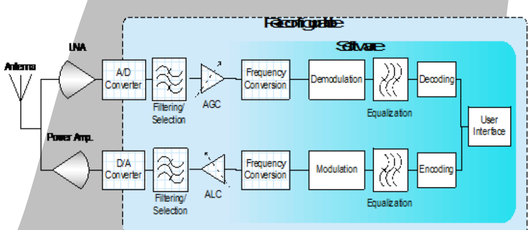




Technology Experiments: 2013 – 2017

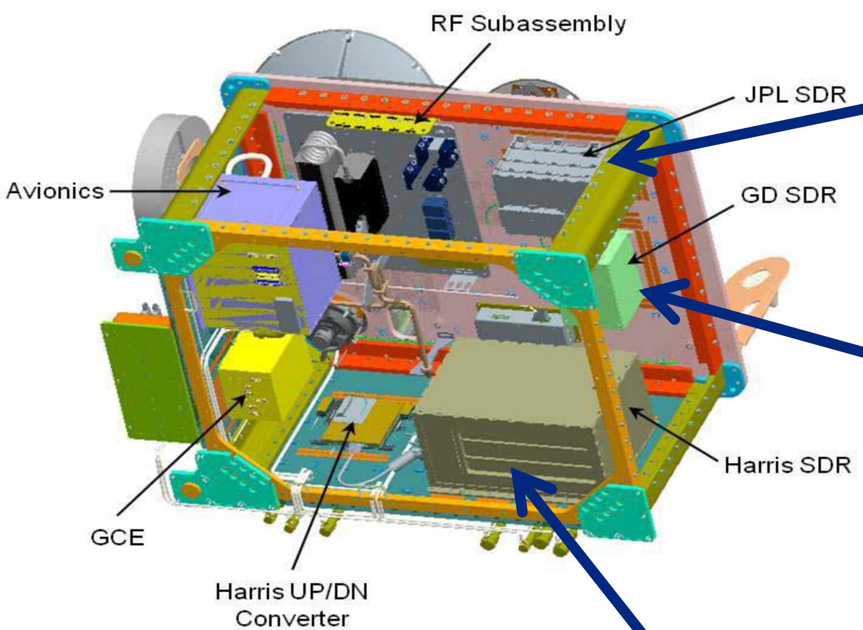
Flight Technology Demonstration: 2008 – 2012
Communications, Navigation and Networking re-Configurable Testbed (CoNNeCT) Project, now known as SCaN Testbed, established to perform system prototype demonstration in relevant environment (TRL-7)

SDR Technology Development: 2005 – 2007
Development of design tools and validation test beds.
Development of design reference implementations and waveform components.
Establish SDR Technology Validation Laboratory at GRC.
NASA/Industry Workshops conducted



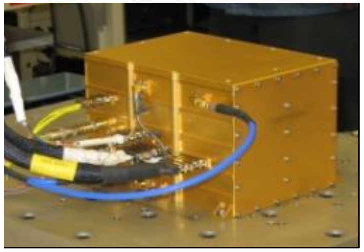
Open Architecture Development and Concept Formulation: 2002 – 2005
Develop common, open standard architecture for space-based software defined radio (SDR) known as Space Telecommunications Radio Architecture (STRS).
Allow reconfigurable communication and navigation functions implemented in software to provide capability to change radio use during mission or after launch.
NASA Multi-Center SDR Architecture Team formed.

The SCaN Testbed has flown several Software-Defined Radios (SDRs)



JPL/L-3 CE

- S-band SDR
  - 6 MHz wide channel
- L-band receive (GPS)
- Virtex II, Sparc Processor, RTEMs
- 10 Mbps Class
- STRS Compliant



General Dynamics

- S-band SDR
  - 6 MHz wide channel
- Virtex II, ColdFire Processor (60 MIPS), VxWorks, CRAM (Chalcogenide RAM) Memory
- 10 Mbps Class
- STRS Compliant

Harris

- Ka-band SDR
  - 225 MHz wide channel
- Virtex IV, PowerPC Proc, DSP (1 GFLOP), VxWorks
- >500 Mbps Class
- STRS Compliant

SDRs offer economies-of-scale via common HW, tailored to mission needs via STRS-compliant software

IWAT 2016

SCaN Testbed Experiments Validate Next Generation Capabilities via New STRS-Compliant Waveforms for SDRs

• Ka/S band System emulation for Space Based Relay

• GPS L1, L2c, L5 orbit fix and validation
• Improved GPS solutions with comm link data fusion.
•Scintillation, jammer detector

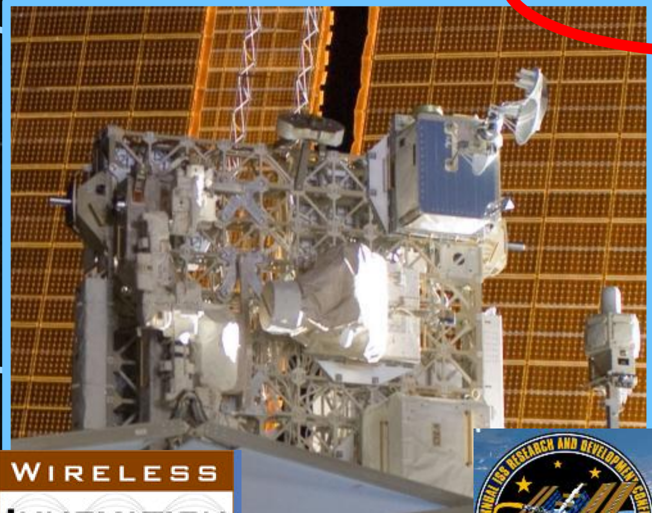
• Space based networking, including DTN, & security

• Potential SDRs for lunar landers, rovers, EVA

•Bandwidth efficient waveforms reduce spectrum use

• SDRs for future TDRS Transponders

• Ka/S System for TDRSS K,/ L function, performance validation
•1st NASA Ka TDRSS User



WIRELESS INNOVATION FORUM

SCaN Payload on ISS
Ka,- S-, and L band

•Cognitive applications enable next generation comm. Sensing, interference mitigation

•Validation and on-orbit user for WSC testing

Completed
Ongoing

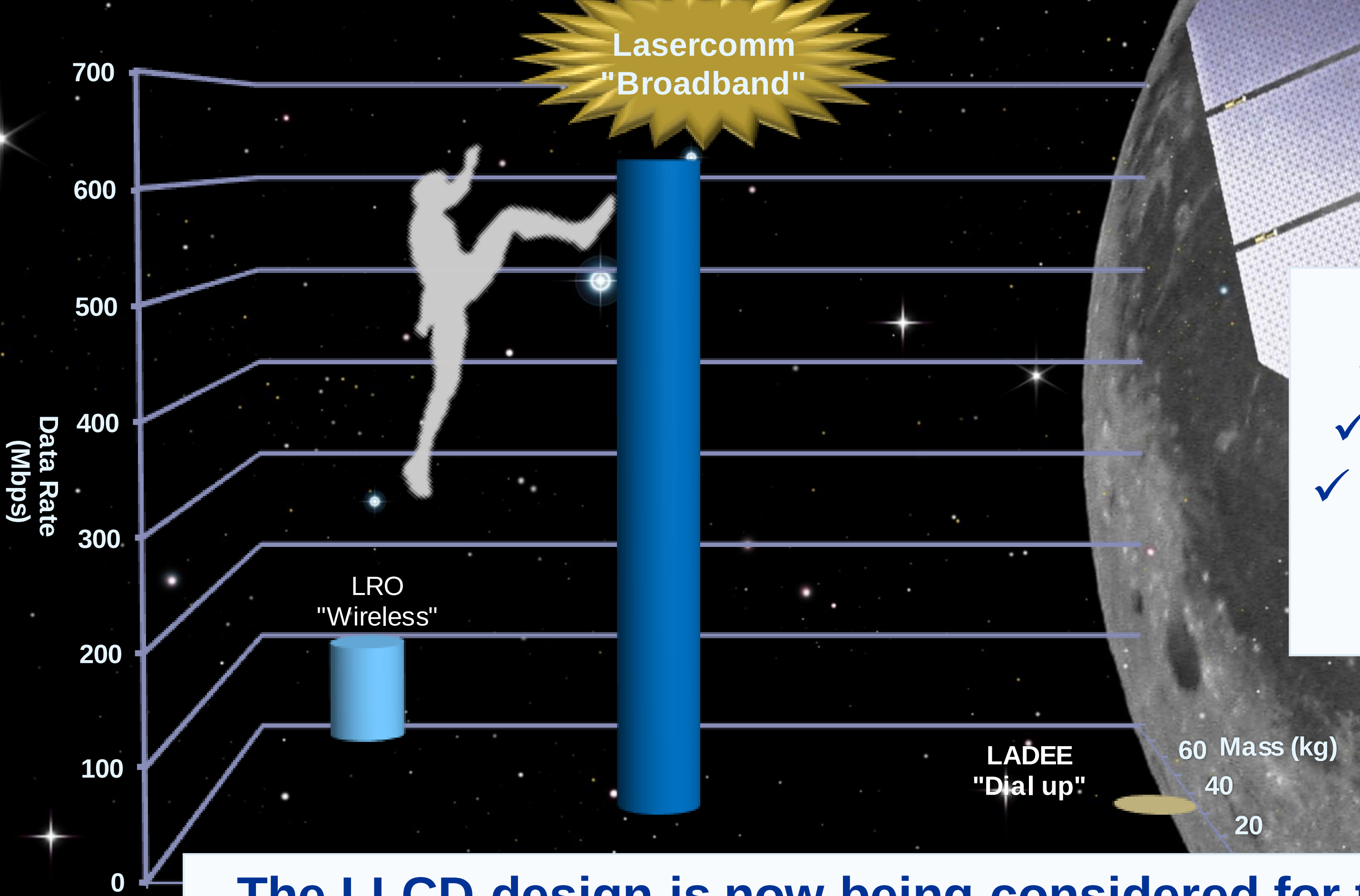
SDR/STRS technology advancement to TRL-7
•New processing capacity

R&D 100

Optical Communications

Lasercomm – Higher Performance AND Increased Efficiency

A Giant Leap in Data Rate Performance for less Mass and Power



LLCD used:

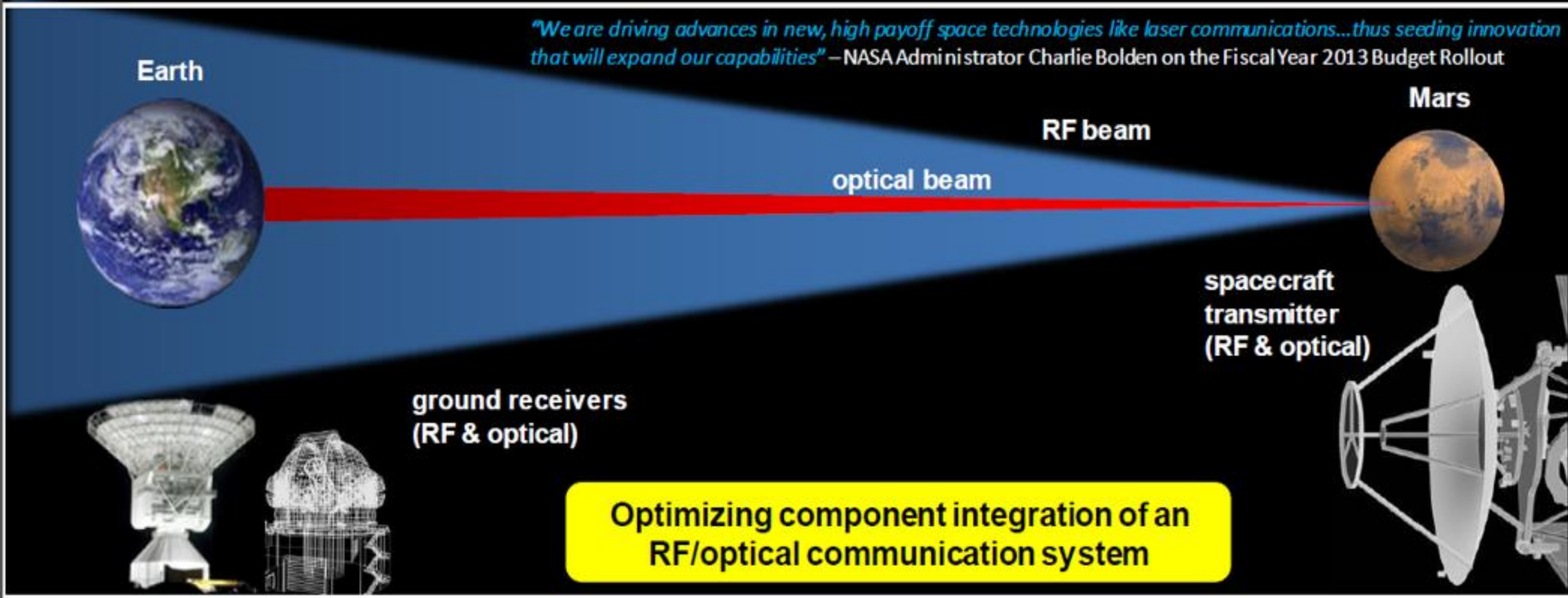
- ✓ Half the mass
- ✓ 25% less power
- ✓ While sending 6x more data than radio…

The LLCD design is now being considered for the Orion vehicle that will take humans to deep space

SCaN Integrated Radio and Optical Communications (iROC)

The integrated RF/optical approach:

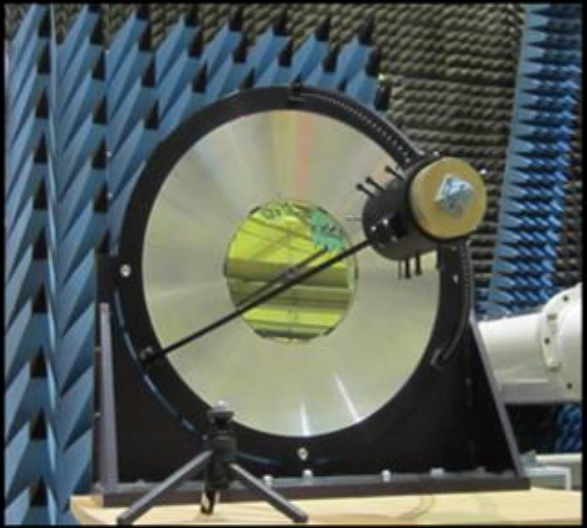
- Accelerates Gbps networked communication service through realizing a secure dual-band deep space trunk line, will not limit deep space science mission data return
- Offers an evolutionary approach to develop the operational readiness of optical communications technology for SCaN's integrated network architecture, while utilizing RF infrastructure to provide availability and redundancy



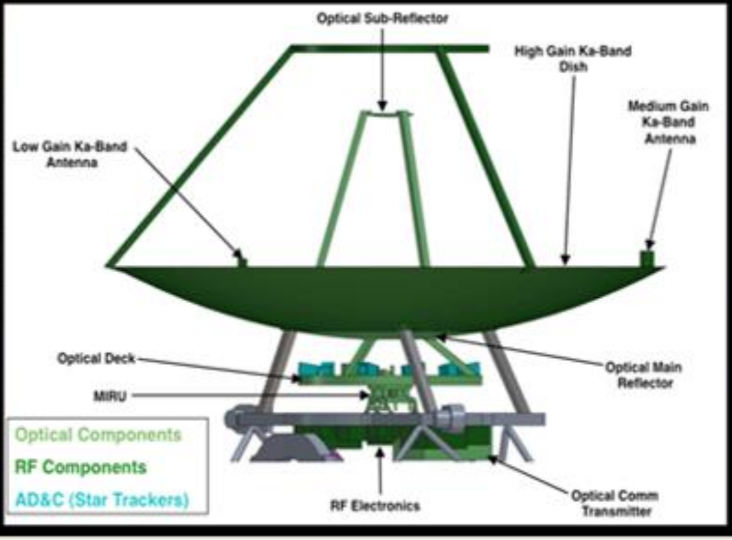
iROC Pointing, Acquisition and Tracking and the Hybrid RF/Optical Aperture are Highly Coupled

- Alternative concept to historical methodology relying on closed-loop tracking on Earth ground station beacon, resulting in increased spacecraft autonomy and extensibility to other deep space missions
- Relies on spacecraft state estimate, attitude knowledge obtained via star trackers
- Preliminary results show sufficient accuracy when solving attitude from estimates from each star tracker, as a function of number of star trackers and time-integrated measurements – technology has developed to the point of beacon consideration
- Derive test bed equipment using multi-camera concept and “star-field”

Prototype Teletenna

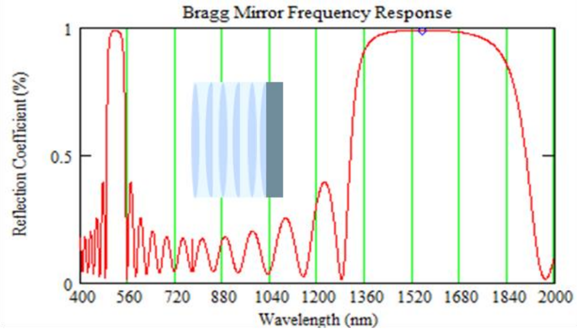


Telescope + Antenna = Teletenna

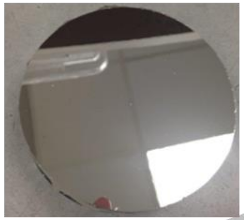


Beaconless Pointing Test- In Work

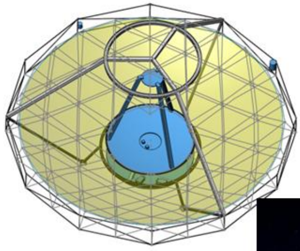
Integrated Radio Optical Communications— “Teletenna Concept”



GRC developed microwave transparent Bragg optical sub-reflector



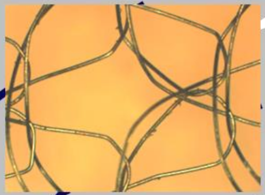
doubly curved graphite skin/aluminum core mirror coupons



Integrated Teletenna System

Large Deployable Mesh Antennas for Deep-Space Communications (NGST SMAP shown)

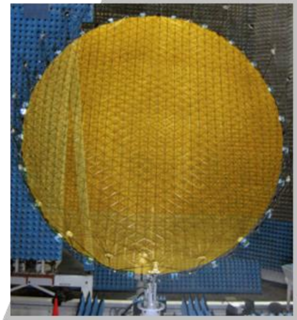
GRC/MicroEngineered Metals process developed to achieve <30 Å surface finish



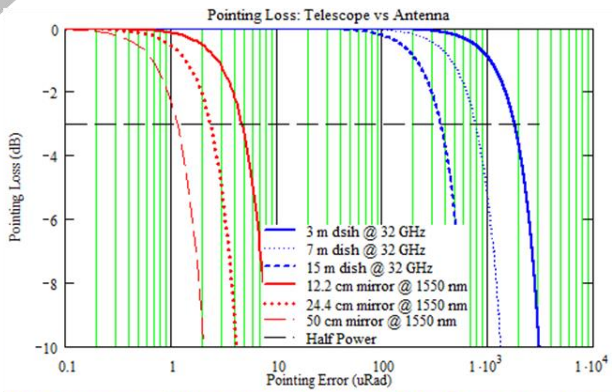
Knitted gold plated molybdenum mesh >98% reflective at Ka-band.

3 m Radio Antenna Material	25 cm Optical Mirror Material	Total Mass (kg)
Composite (16.7 kg)	Beryllium (0.5 kg)	17.2
Composite (16.7 kg)	Composite (0.1 kg)	16.8
Mesh (7.5 kg)	Composite (0.1 kg)	7.6

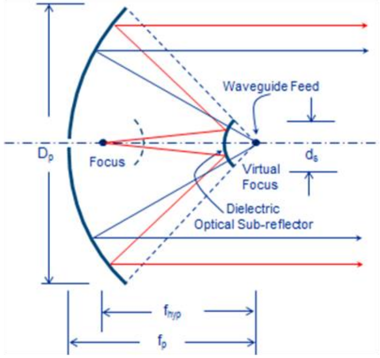
Teletenna material options and associated mass



Northrop Grumman 5.2 m Astromesh Reflector Characterized at GRC in 2008



Telescope and Antenna Beam-widths/Pointing Loss

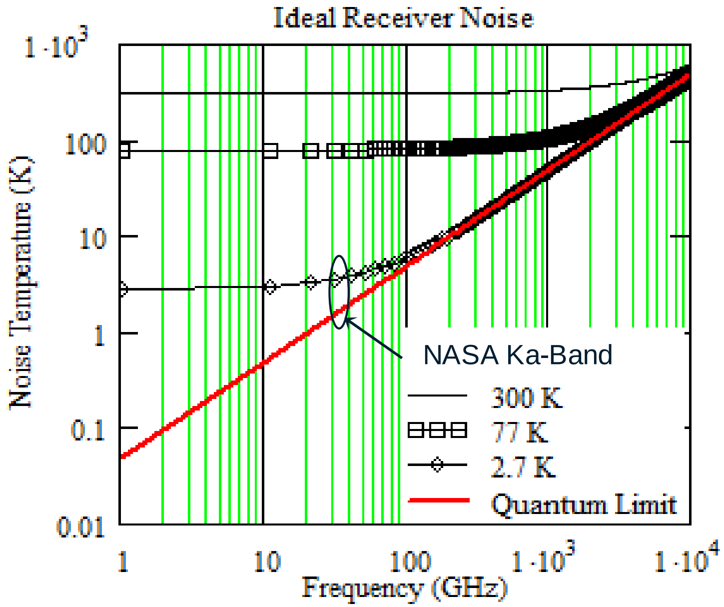


Hybrid Cassegrain/Prime Focus Telescope & antenna concept

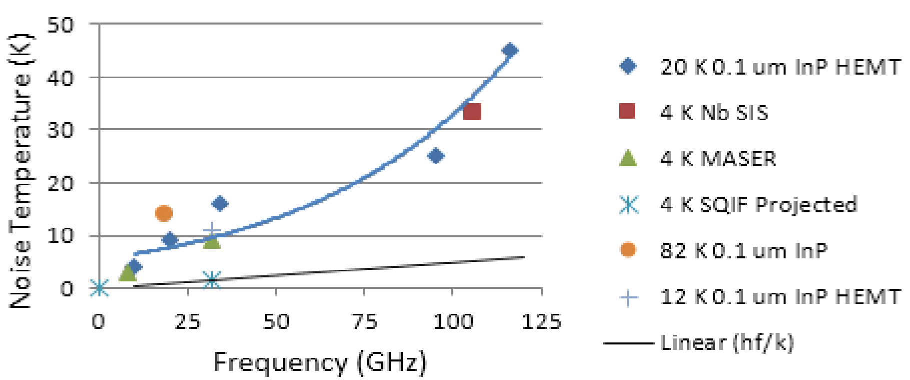
Superconducting Quantum Interference Filter (SQIF)-Based Microwave Receivers

Superconducting Quantum Interference Filter-Based Microwave Receivers

- Use magnetic instead of electric field detection to take advantage of highly sensitive Superconducting Quantum Interference Device (SQUID) arrays.
  - Proven and being used in medical and physics research, geology, etc.
- SQUIDs have a typical energy sensitivity per unit bandwidth of about 10^6 h or $\approx 10^{-28}$ J.
- Conventional semiconductor electric field detection threshold of $\sim kT \approx 10^{-22}$ J.

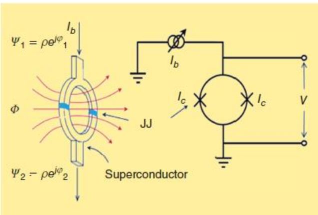


State-of-the-Art Cooled Low Noise Amplifiers

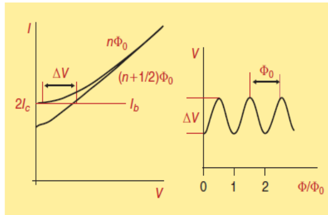


Superconducting Quantum Interference Filter (SQIF)

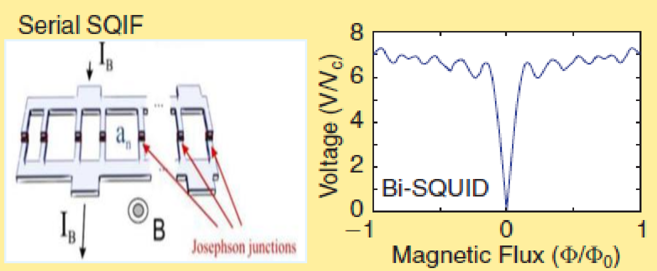
Operating Principles



A single SQUID



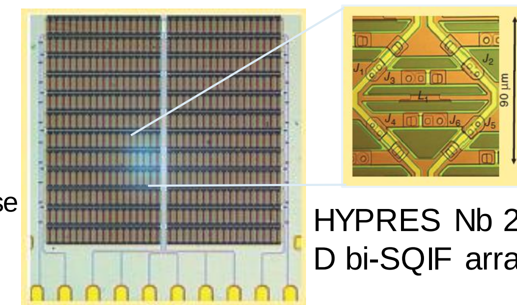
Periodic flux-to-voltage response



(a) (b)

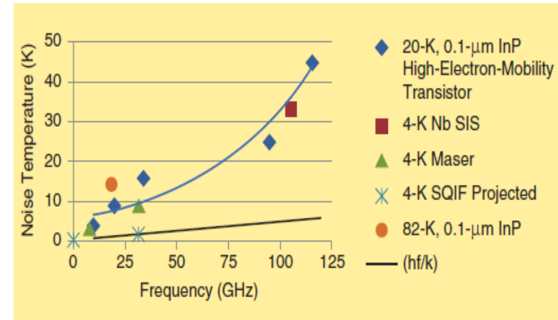
- SQUID voltage response is periodic in the applied magnetic field
- SQIF is an array of SQUIDs of incommensurate area with a unique magnetic flux-to-voltage response
- Sensitivity improves with arraying more cells (S/N ~ $\sqrt{N}$)

Integrated circuit of 2-D SQIF arrays

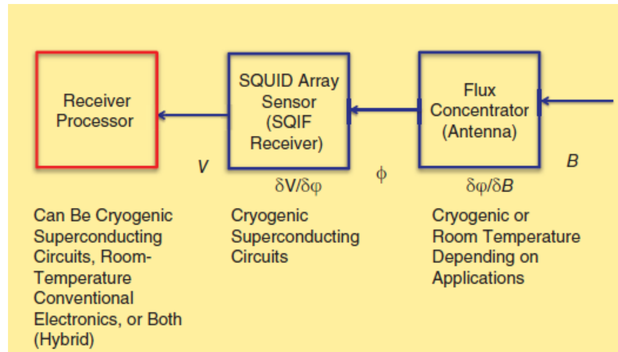


HYPRES Nb 2-D bi-SQIF array

Comparative Technologies



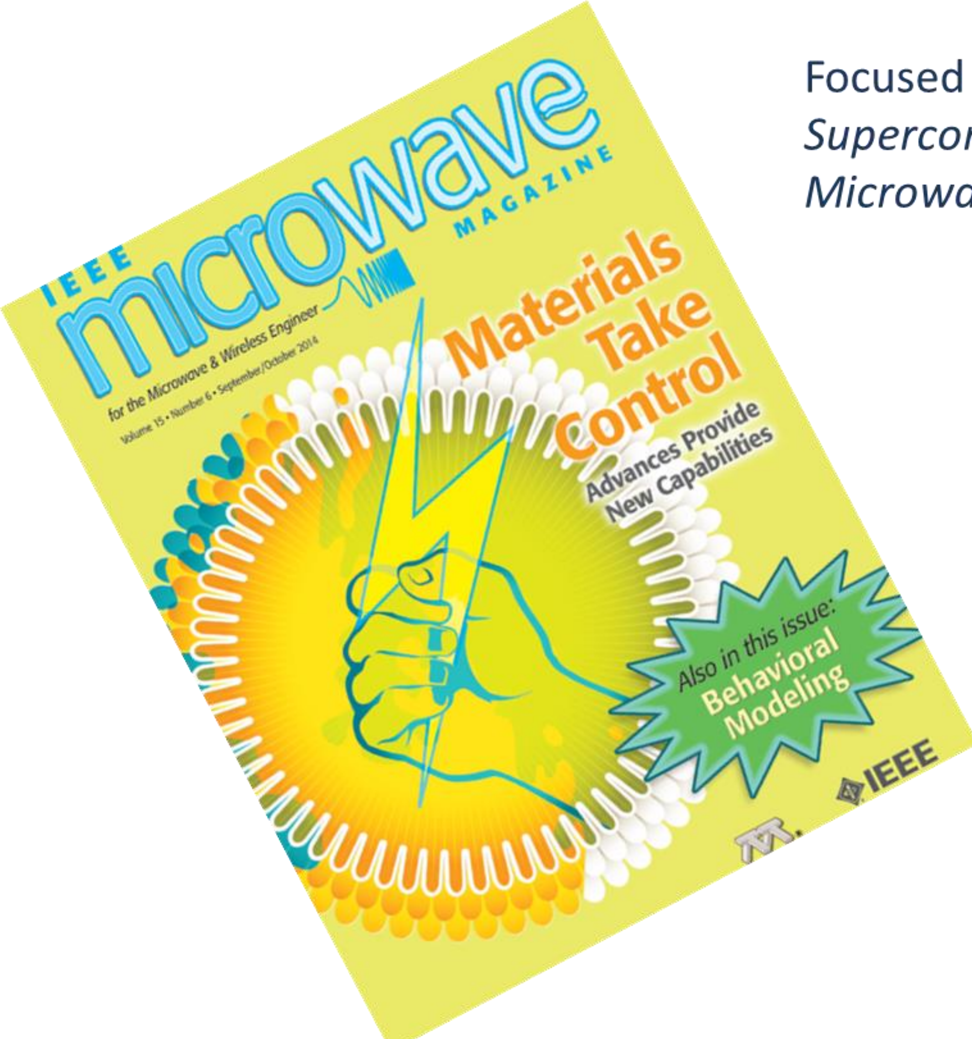
SQIF receiver conceptual block diagram



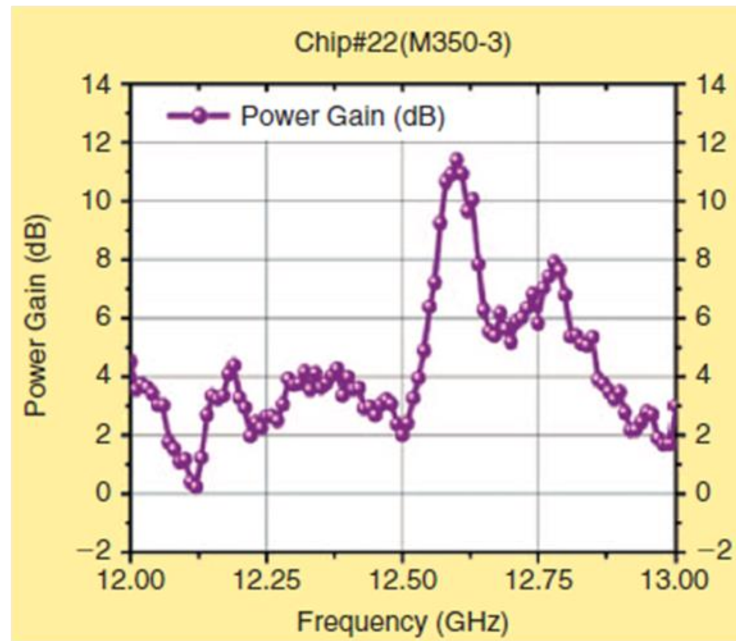
- Receiver will consist of a flux concentrator (antenna), SQIF sensor, and digital signal processor

- Energy sensitivity of about 10^{-31} J/Hz, compared to semiconductor 10^{-22} J
- Sensitivity approaches quantum limit, while increasing dynamic range and linearity
- Attractive for wideband-sensitive receivers
- Robust to variation in fabrication spread (e.g. junction critical current, inductance, etc.)

Quantum Sensitivity: Superconducting Quantum Interference Filter-Based Microwave Receivers



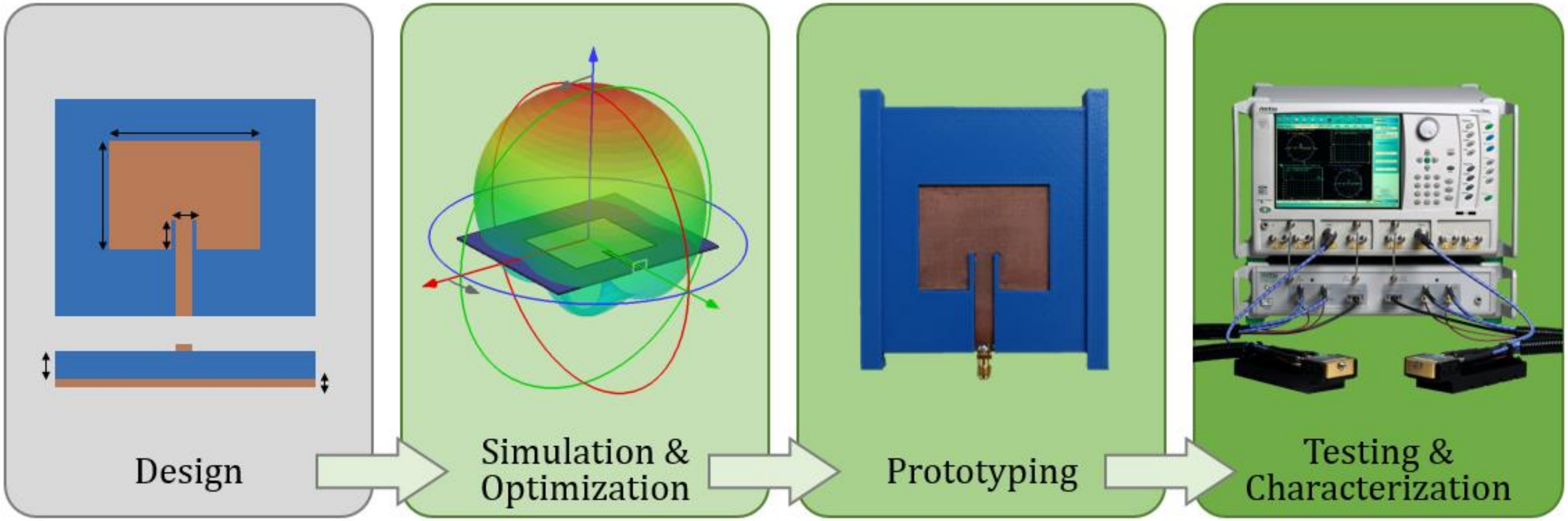
Focused Issue Featured Article: *Quantum Sensitivity: Superconducting Quantum Interference Filter-Based Microwave Receivers*



First reported X-band SQIF performance…

3D Printed Antennas for Cubesats/Smallsats Applications

Antenna Rapid Prototyping and Characterization Capabilities



- CST Microwave Studio
- Ansys HFSS
- IE3D

- Traditional CNC, Lithography, Laminate Etching
- Material Extrusion 3D Printing (Stratasys uPrint SE)
- Advanced Laser Etching (LPKF ProtoLaser U3)

- Far-Field , Near Field, and Compact Antenna Ranges; Near-Field Probe Station
- Vector Network Analyzers up to 110 GHz
- Signal Generators up to 90 GHz

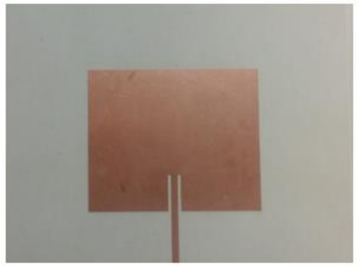
Complete Rapid Prototyping Capability in-house at Glenn Research Center

Antenna Rapid Prototyping and Characterization Capabilities

Examples of Prototypes

Planar Patches

Copper Mesh



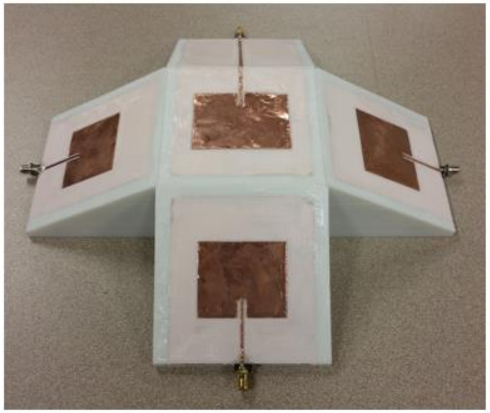
Duroid 5880

Copper Foil

Duroid 6010

Offset Planar Patches

Copper Mesh / Copper Foil



Copper Foil

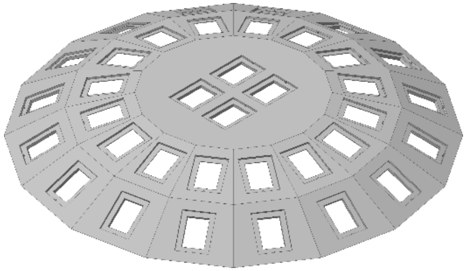
Conformal Patches

Copper Mesh

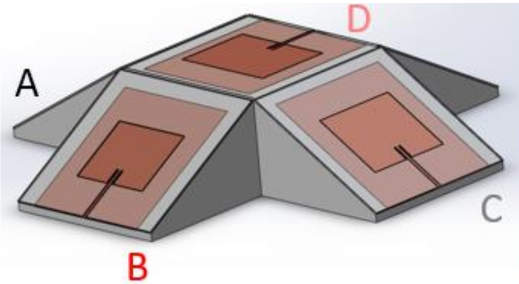
Copper Foil

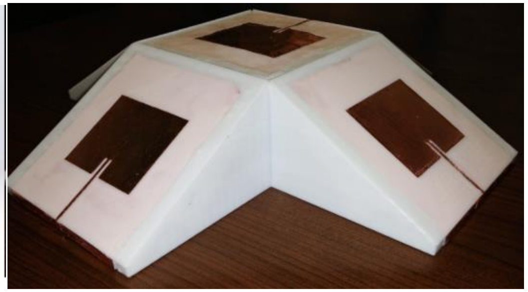
Switched Array

360° Az, 30° El Coverage

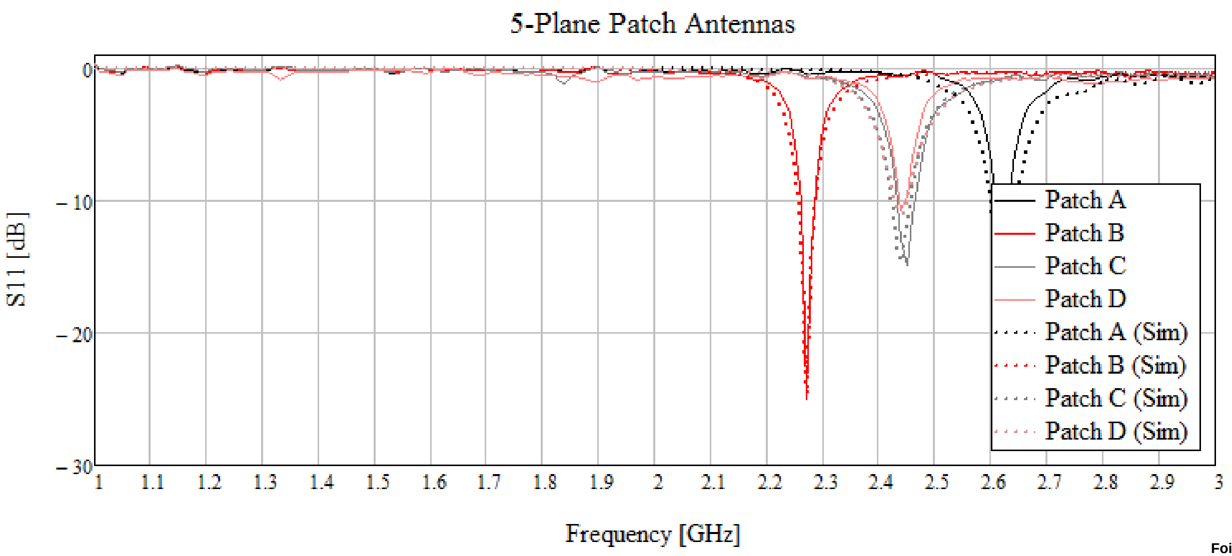


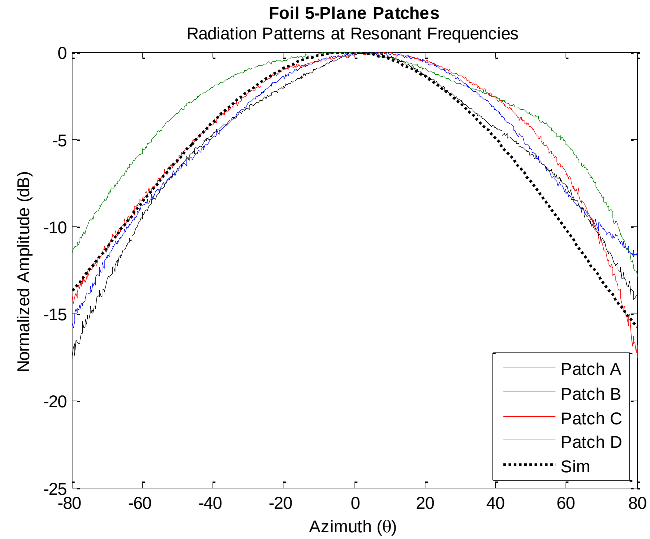
Measurement & Characterization

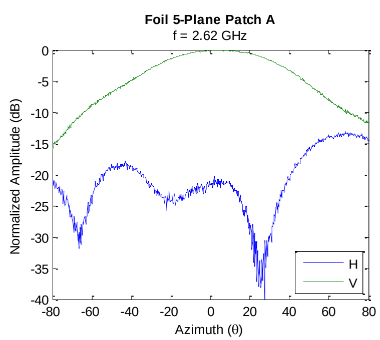


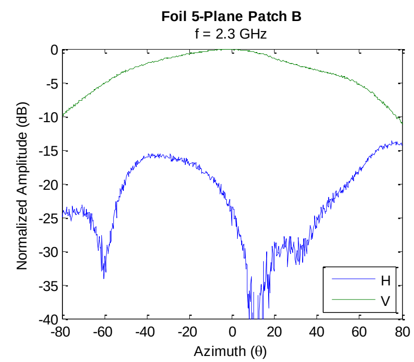


- Scattering Parameters / Return Loss
- Radiation Patterns
- Co- and Cross-Polarizations

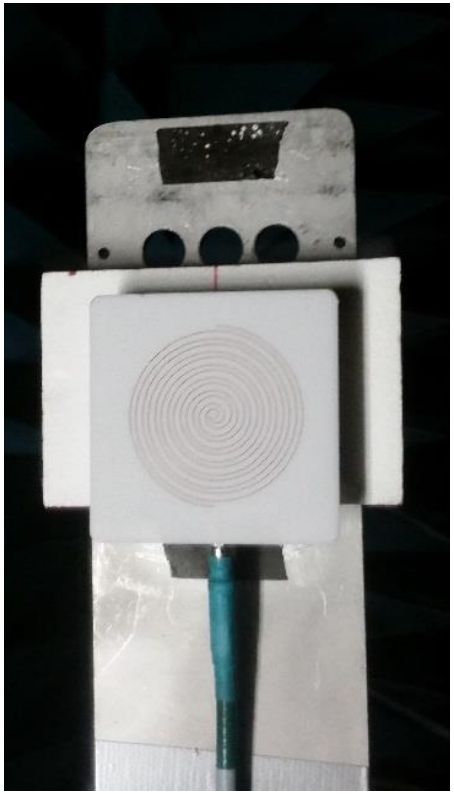


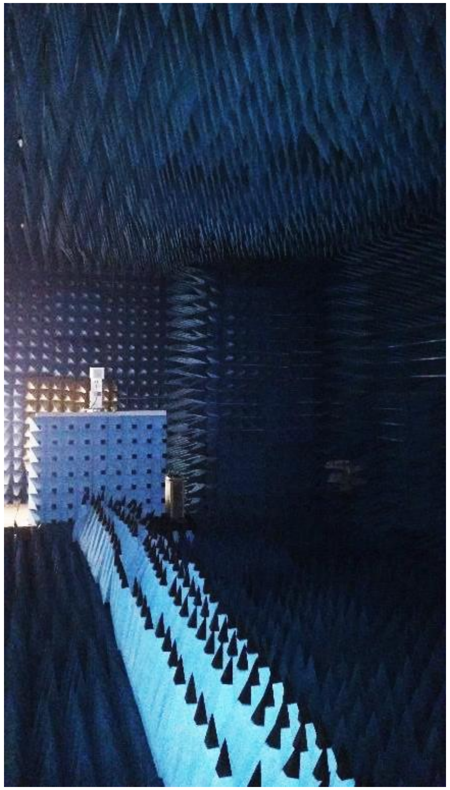






3D Printed Antennas – Archimedean Spiral





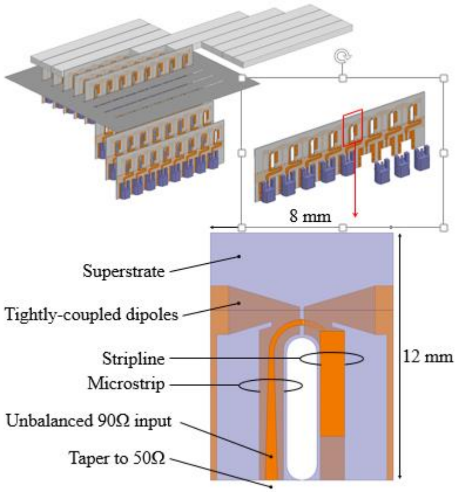
The embedded Archimedean spiral antenna under test in the NASA Glenn Research Center far-field antenna range.

- Demonstrate novel additive manufacturing technologies as applied to cubesat / small sat applications.
  - Embed antennas and associated electronics within cubesat walls to maximize use of real estate.
  - Increased customizability/rapid prototyping of designs.
- Archimedean spiral dipole design used to demonstrate wire embedding and several alternative balun implementations.
  - Duroid balun affixed after printing.
  - Duroid balun embedded into structure during printing.
  - Copper mesh balun embedded during printing, using polycarbonate substrate as dielectric.

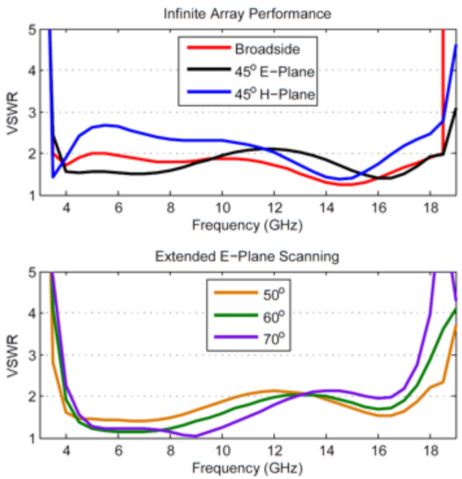
Compact Ultra Wide Band Antennas

Miniature, Conformal and Spectrally Agile Ultra Wideband (UWB) Phased Array Antenna for Communication and Sensing

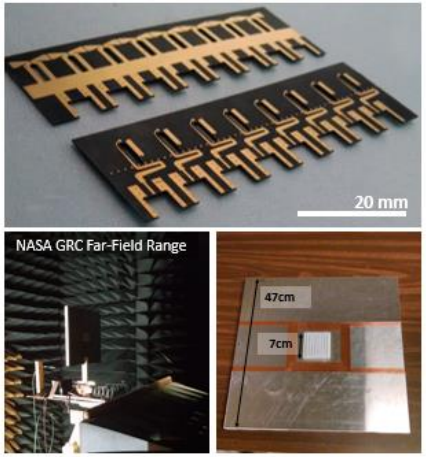
Tight Coupled Dipole Array (TCDA)



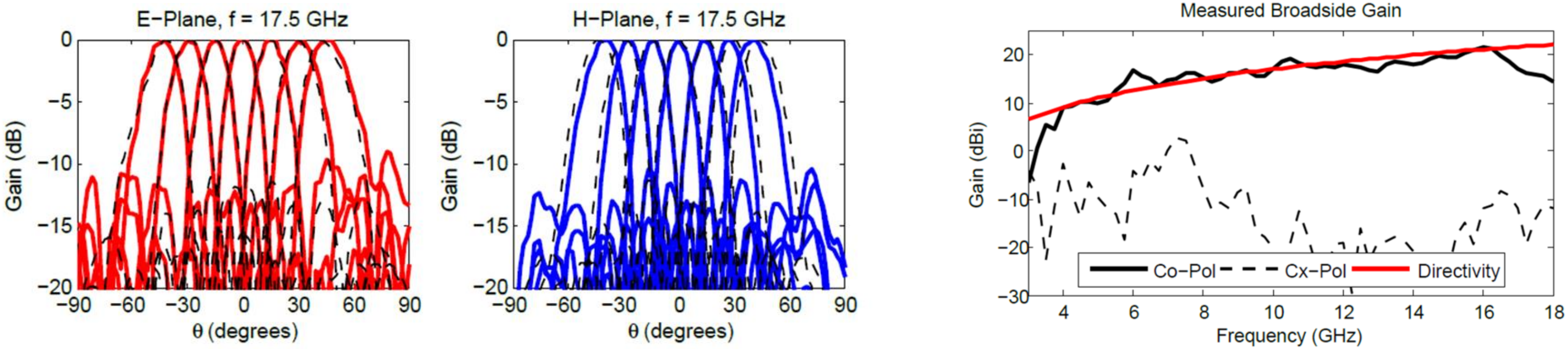
Simulations



TCDA Fabrication and Characterization



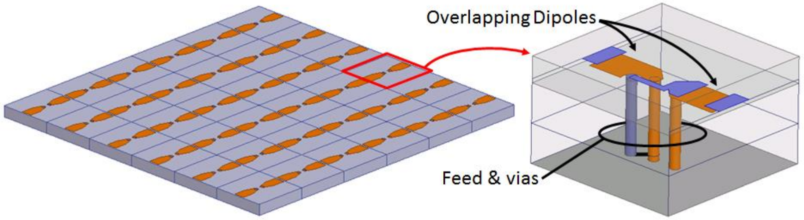
Experimental Results

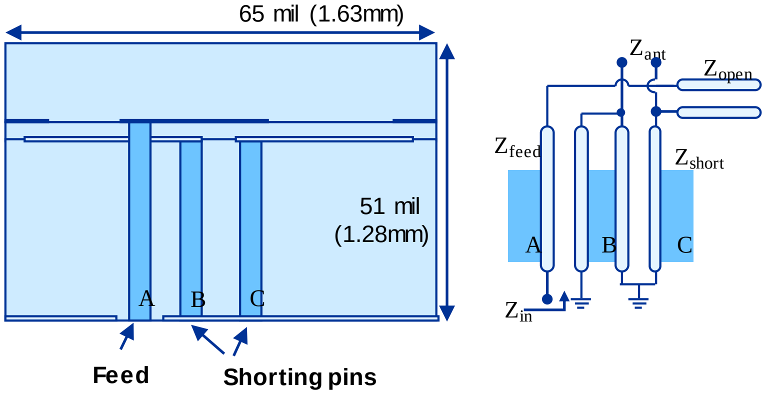


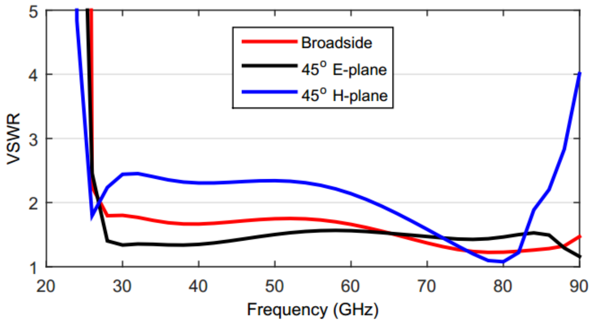
Ref: "Wide Band Array for C-, X-, and Ku-Band Applications with 5.3:1 Bandwidth," Markus H. Novak, John L. Volakis, and Félix A. Miranda, 2015 International Symposium on Antennas and Propagation, July 19-25, 2015, Vancouver, CANADA

Miniature, Conformal and Spectrally Agile Ultra Wideband (UWB) Phased Array Antenna for Communication and Sensing

Planar TCDA for Millimeter-Wave Applications







- 26 GHz–86 GHz with VSWR<1.8 at broadside
- Min. feature size: 3 mil (76um)
- Designed for PCB fabrication

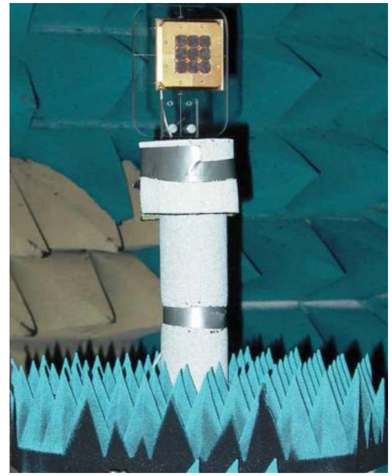
Ref: "Low Cost Ultra-Wideband Millimeter-Wave Array," Markus H. Novak, John L. Volakis, and Félix A. Miranda, 2016 International Symposium on Antennas and Propagation, Fajardo, Puerto Rico.

Wide Band Antenna for Wideband Instrument for Snow Measurements (WISM)

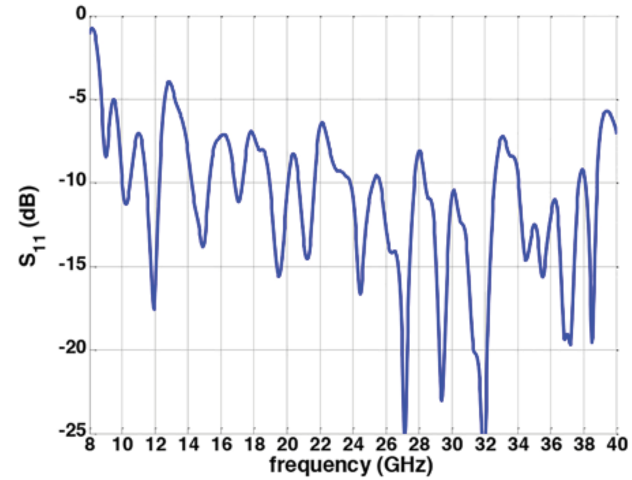
Objective:

- Advance the utility of a wideband active and passive instrument (8-40 GHz) to support the snow science community
- Improve snow measurements through advanced calibration and expanded frequency of active and passive sensors
- Demonstrate science utility through airborne retrievals of snow water equivalent (SWE)
- Advance the technology readiness of broadband current sheet array (CSA) antenna technology for spaceflight applications

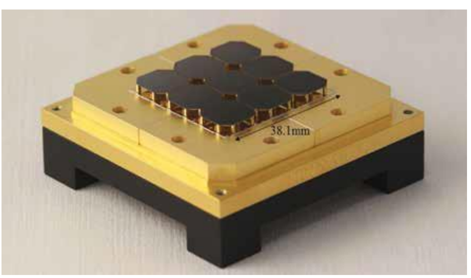
A CSA (current sheet antenna), consisting of a small, 6x6 element, dual-linear polarized array with integrated beamformer, feeds an offset parabolic reflector, enabling WISM operation over an 8 to 40 GHz frequency band.



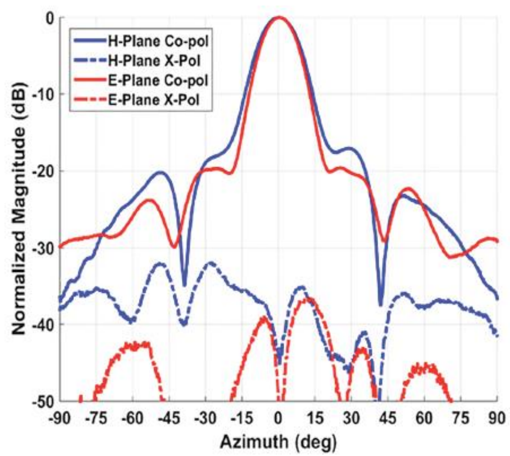
WISM antenna in GRC Far Field Range



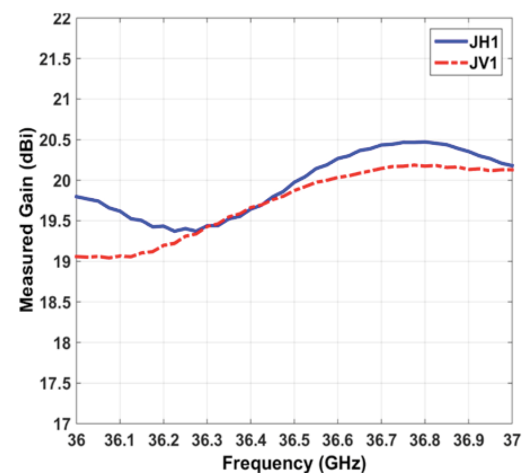
Feed return loss.



Photograph of the final WISM antenna feed design. Outer dimensions of the antenna are 71.1 by 71.1 mm, although the PolyStrata (Nuvotronics, Inc.) portion is 38.1 mm on each side.



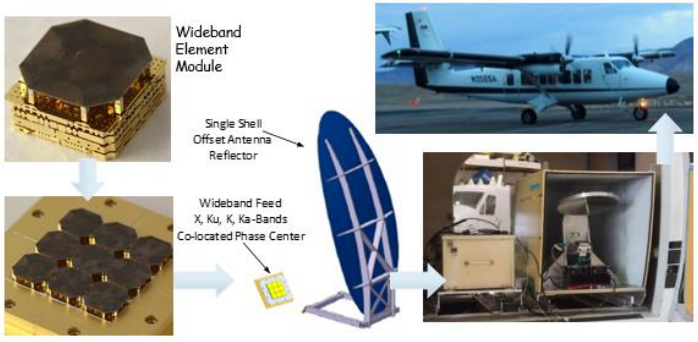
Feed principal plane patterns at 36.5 GHz.



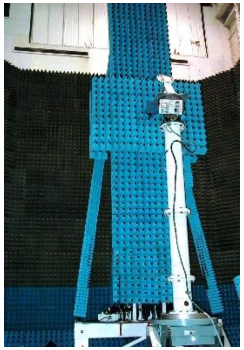
Feed Ka-band gain.

Wide Band Antenna for Wideband Instrument for Snow Measurements (WISM)

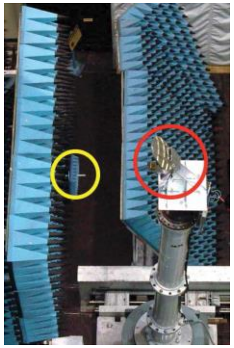
Reflector System Integration, alignment and Characterization



Enabled by advanced CSA technology, WISM is a new broadband multi-function research instrument for NASA's snow remote sensing community

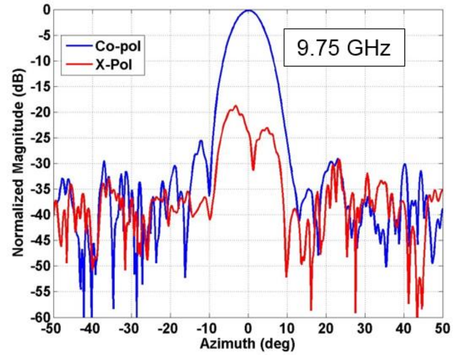


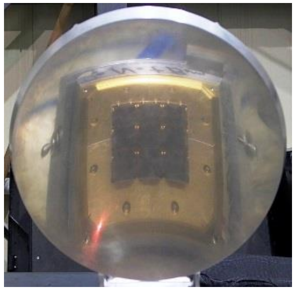
Antenna and vertical scanner of GRC Near Field Range .



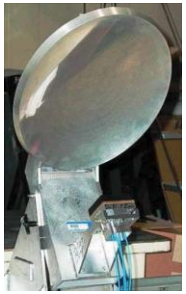
Top view of antenna and near-field probe.

Principal Plane Pattern

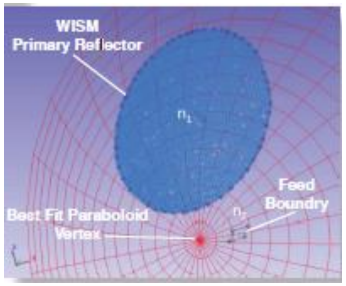




Laser radar used to ensure proper feed alignment.

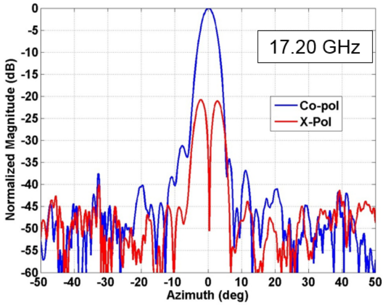


WISM reflector antenna with WISM antenna feed

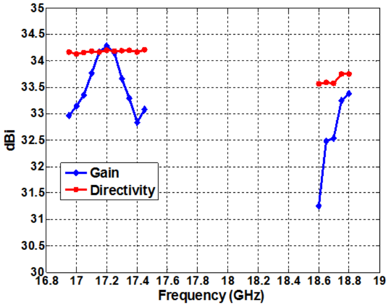


Primary reflector surface map, feed plane, and parent parabola; n_1 is the normal to the WISM reflector, centered at the vertex, and n_2 is the normal to the feed plane.

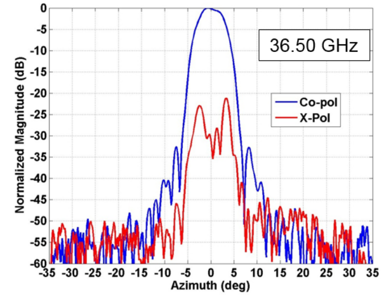
Principal Plane Pattern



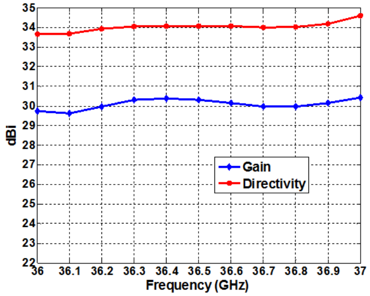
Directivity and Gain



Principal Plane Pattern



Directivity and Gain

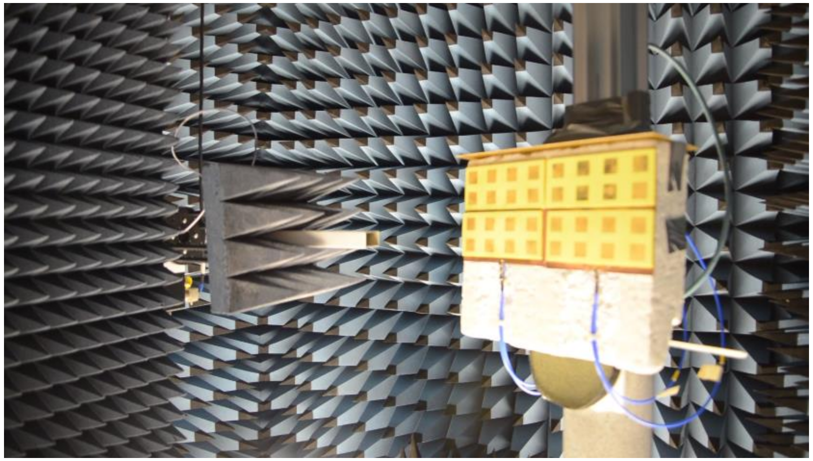


Ref: "Antenna Characterization for the Wideband Instrument for Snow Measurements," Kevin M. Lambert, Félix A. Miranda, Robert R. Romanofsky, Timothy E. Durham, and Kenneth J. Vanhille, 2015 International Symposium on Antennas and Propagation, July 19-25, 2015, Vancouver, CANADA

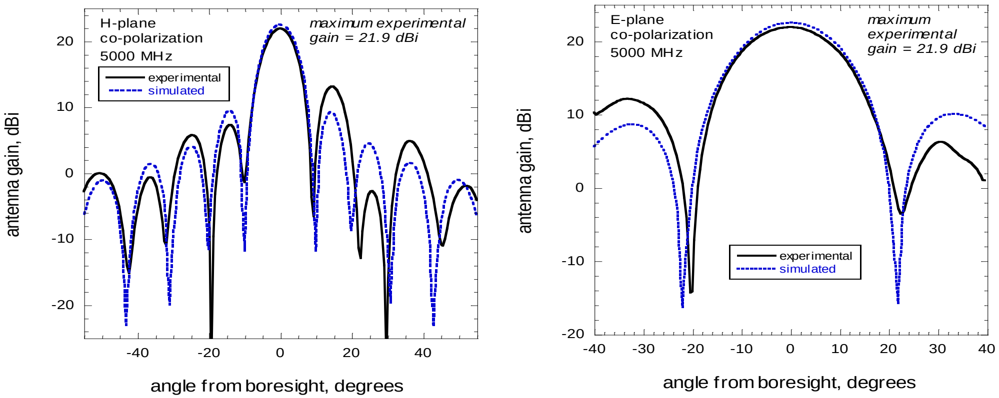
Other Antenna Concepts

32 element Aerogel Antenna Array

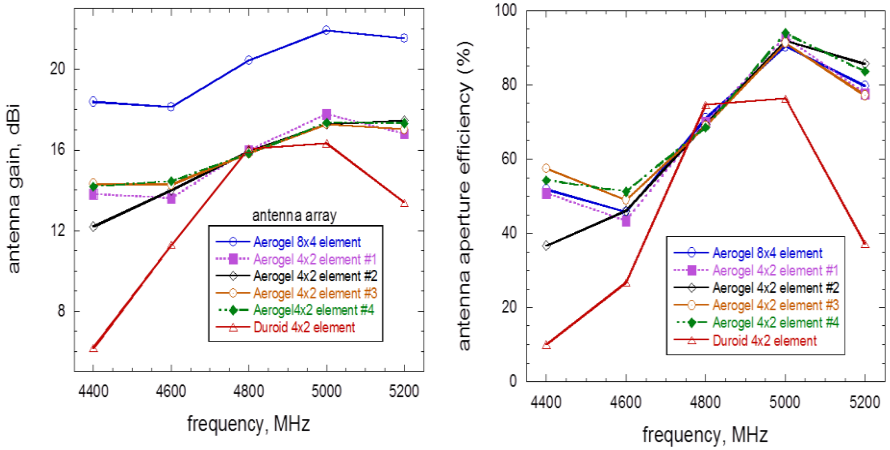
- Testing of 32 element array
- Shows scalability of aerogel antenna performance. Tile approach used to increase physical aperture size and increase gain



Gain *vs.* angle from boresight
(Simulated and experimental)



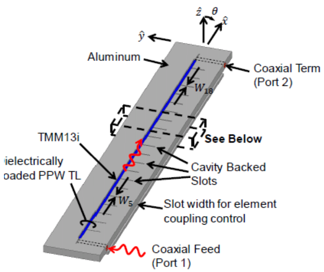
Comparative Antenna Grain and
Aperture Efficency

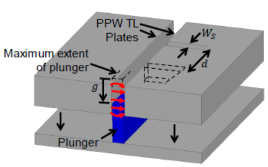


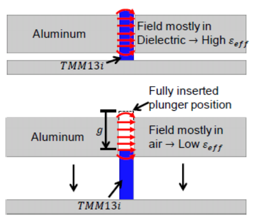
Ref: "Aerogel Antenna Communications Study using Error Vector Magnitude Measurements," Félix A. Miranda, Carl H. Mueller and Mary Ann B. Meador, 2014 International Symposium on Antennas and Propagation, July 6-11, 2014, Memphis, TN

Ku-Band Traveling Wave Slot Array Using Simple Scanning Control

Operating Principle

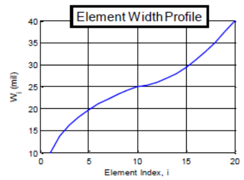


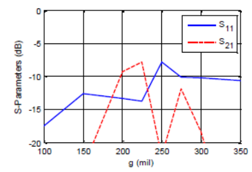


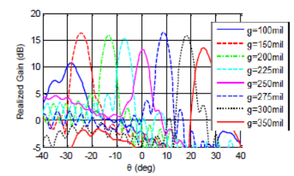


- Array elements fed via propagation reconfigurable transmission line
- k_{eff} reconfigured via small mechanical movement
- Phase delivered to each element a function of k_{eff}
- Array scanned with only the small mechanical movemen

Initial Design Performance

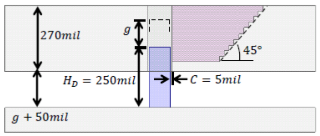


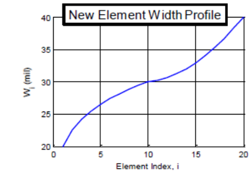




- S-Parameters generally less than $-10dB$ except around boresight scan as expected
- Scanning of $-25° \leq \theta \leq 25°$
- Consistent realized gain level across scan range

Increase Manufacturability



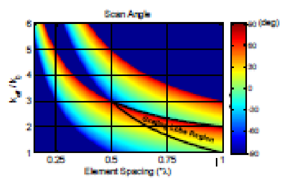


Reduce fabrication complexity

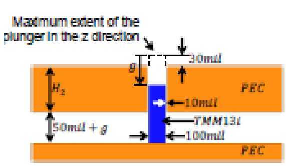
- 10 Steps to approximate cavity back
- Reduced plunger height
- Alter TL geometry and element spacing to achieve desired scan range

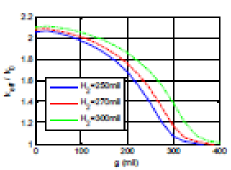
Variable	Initial Design	Final Design
Cavity Back	Straight	Stepped
H_D	350mil	250mil
C	10mil	5mil
Element Spacing	0.65λ	0.54λ

Transmission Line Design

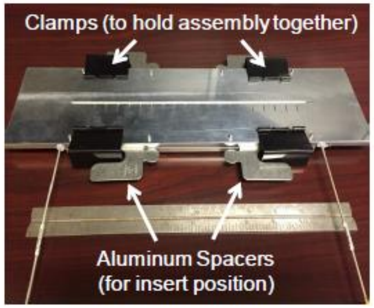


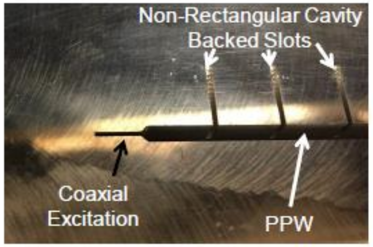
- Scan range a function of element spacing and TL k_{eff}
- $-30° \leq \theta \leq 30°$ scanning is achieved with $1.04 \leq \frac{k_{eff}}{k_0} \leq 2.04$ for and element spacing of 0.65λ
- Line achieves the necessary k_{eff} agility at $H_2 = 270mil$

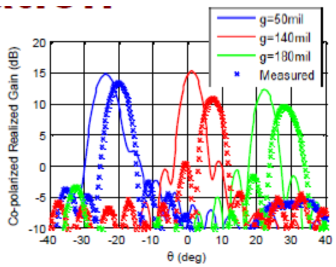




Prototype Validation







- Measurements generally agree with simulation
- Realized gain is down compared to simulated due to differences in TL geometry
- Measured scan angle is more positive, also due to differences in TL geometry

Ref: "Ku Band Traveling Wave Slot Array Using Simple Scanning Control," Nicholas K. Host, Chi-Chih Chen, John L. Volakis, and Félix A. Miranda, 2015 International Symposium on Antennas and Propagation, July 19-25, 2015, Vancouver, CANADA

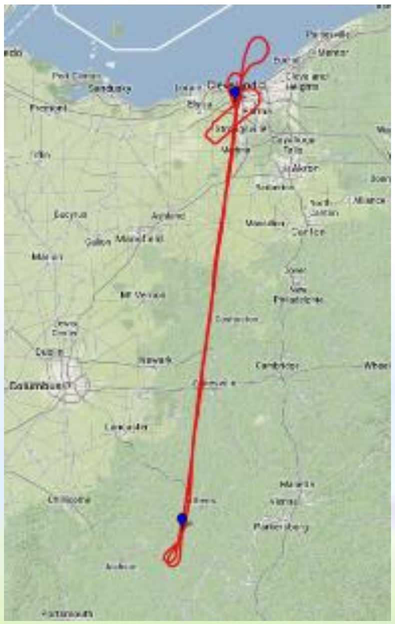
Aerospace Communications

Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

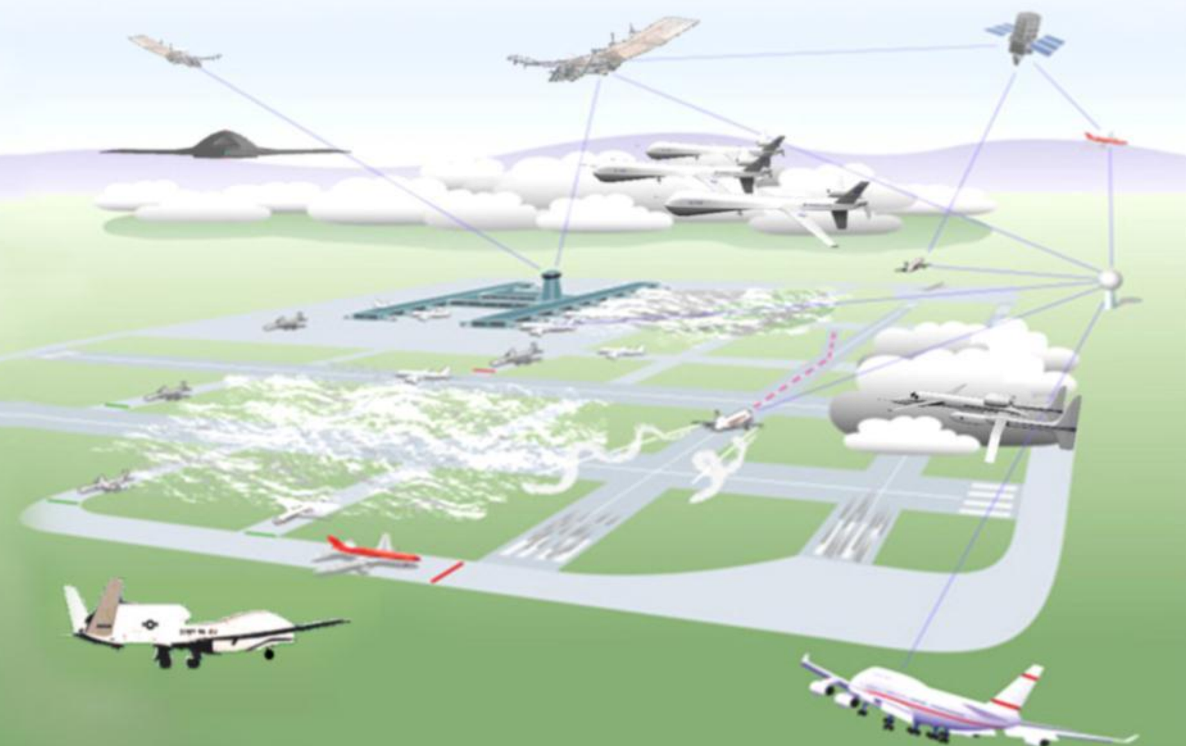
National Aeronautics and Space Administration

Communication Sub-project: Develop Minimum Operational Procedures and Standards (MOPS) for Control and Non-Payload Communications (CNPC) of UAS in the NAS

- L- and C-Band spectrum allocation
- Datalink performance
- Network Security



Flight test performing "handoffs" between GRC and Ohio University Airport ground stations.



Summary

The specific communications technologies needed for future NASA exploration missions to ensure full availability of deep space science mission data returns will depend on:

- Data rate requirements, available frequencies, available space and power, and desired asset-specific services. Likewise, efficiency, mass, and cost will drive decisions.

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