Recent Efforts in Communications Research and Technology at the Glenn Research Center in Support of NASA's Mission

By

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Abstract

As it has done in the past, NASA is currently engaged in furthering the frontiers of space and planetary exploration. The effectiveness in gathering the desired science data in the amount and quality required to perform this pioneering work relies heavily on the communications capabilities of the spacecraft and space platforms being considered to enable future missions. Accordingly, the continuous improvement and development of radiofrequency and optical communications systems are fundamental to prevent communications to become the limiting factor for space explorations. This presentation will discuss some of the research and technology development efforts currently underway at the NASA Glenn Research Center in the radio frequency (RF) and Optical Communications. Examples of work conducted in-house and also in collaboration with academia, industry, and other government agencies (OGA) in areas such as antenna technology, power amplifiers, radio frequency (RF) wave propagation through Earth's atmosphere, ultra-sensitive receivers, thin films ferroelectric-based tunable components, among others, will be presented. In addition, the role of these and other related RF technologies in enabling the NASA next generation space communications architecture will be also discussed.

Outline

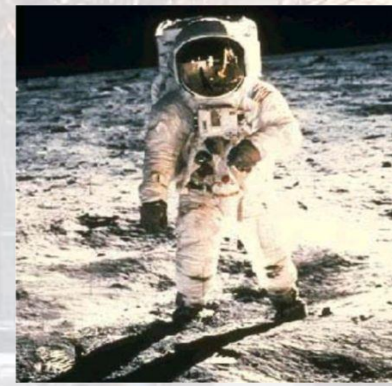
- Importance of communications and supporting capabilities
- Communications and Intelligent Systems
- Examples of Activities in Communications Research and Technology Development
  - RF Propagation
  - Large Aperture Deployable Antennas
  - Phased Array Antennas: Ferroelectric Reflectarray Antenna
  - Power Amplifiers
  - Software Define Radios and STRS architectures
  - Optical Communications
  - SQIF
  - 3D Printed Antennas
- Summary

Importance of Communications

Robotic-based Exploration

Human-based Exploration

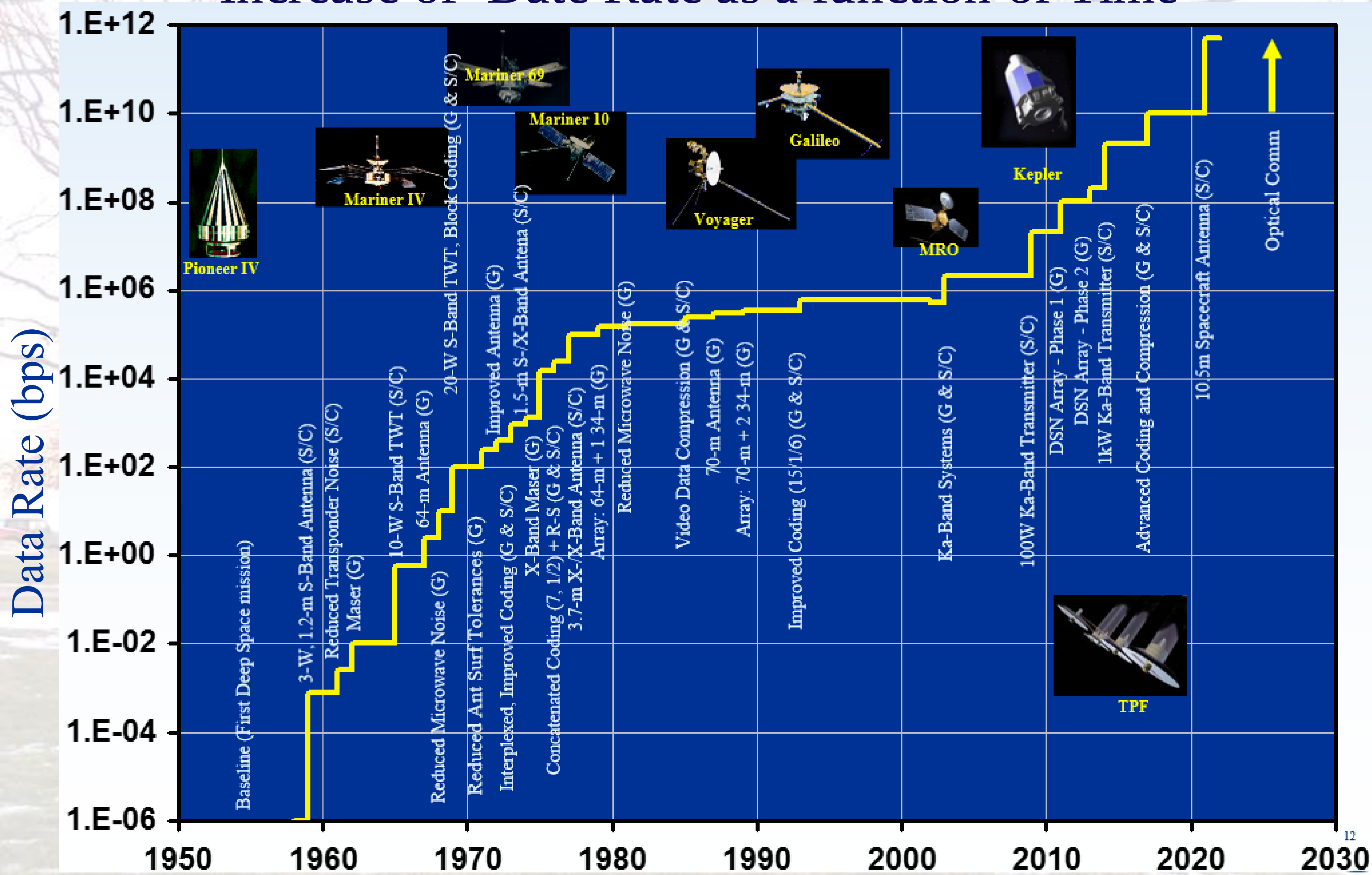
Spacecraft/Satellite-based Exploration



Enable Forward/Return Communications and TT&C with:

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

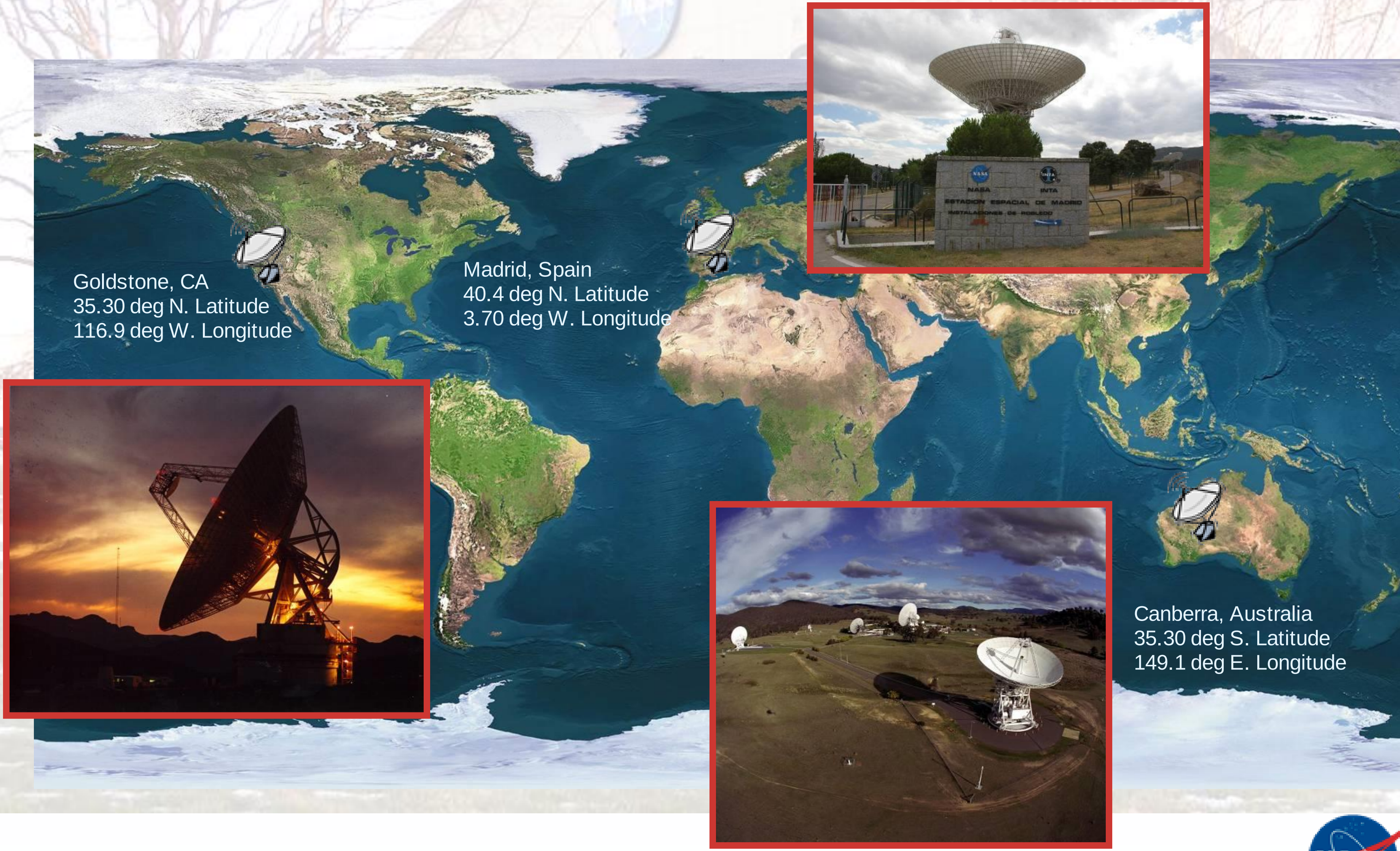
Increase of Date Rate as a function of Time



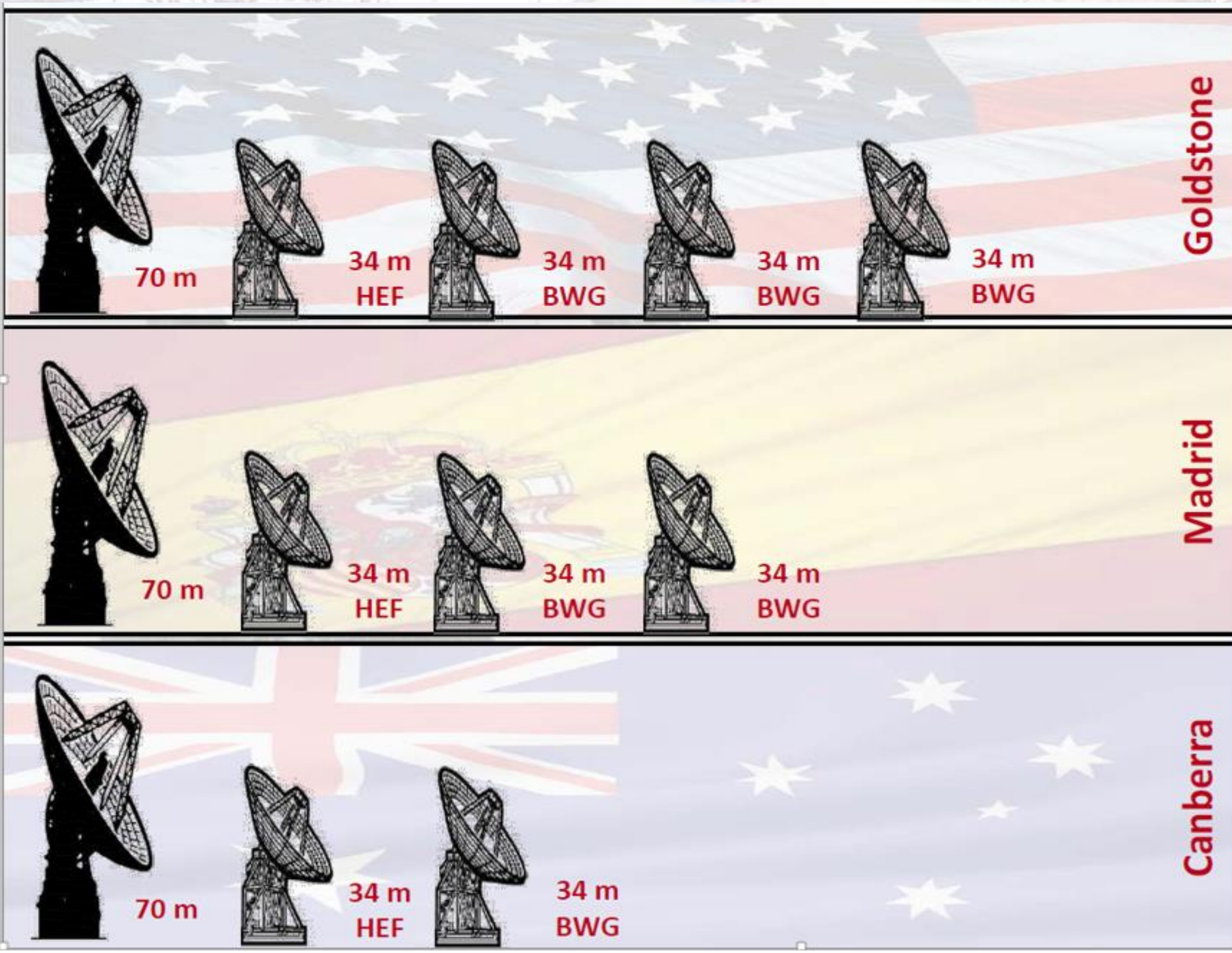
Space Communications and Navigation (SCaN) Operational Network

Deep Space Network | Near Earth Network | Space Network

Deep Space Network (DSN)



Deep Space Network (DSN) Enhancement Project



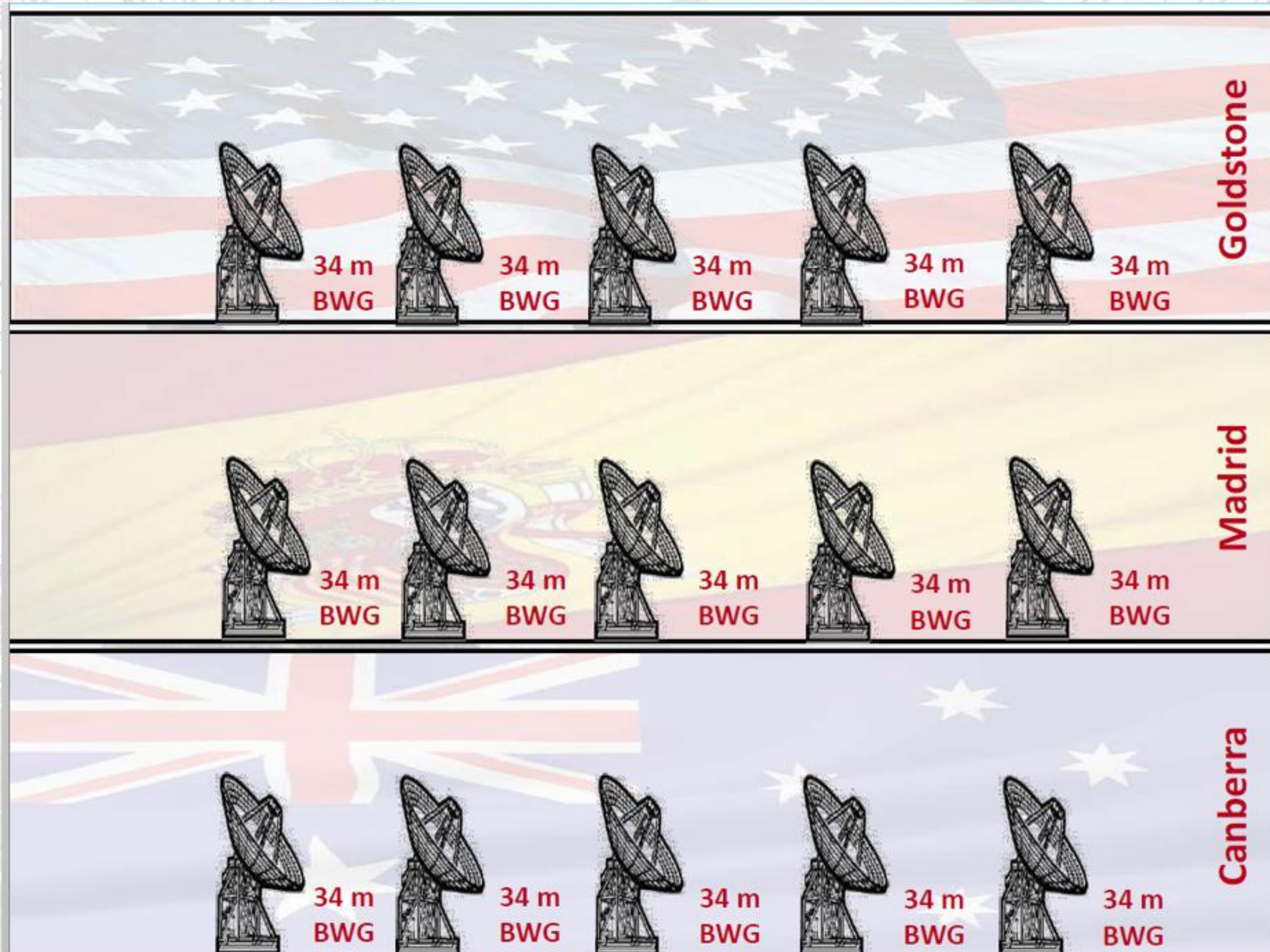
DSN Configuration: Today

Each ground station has:

- one 70m antenna
- one 34m High Efficiency antenna (HEF)
- one or more Beam Wave Guide (BWG) antennas.

- HEF antennas were built in the 1980's and were the first to support X-band uplink.
- BWG antennas were built in the 1990's and route energy between the reflector and a room below ground which allows for many feeds and amplifiers at multiple frequencies to be illuminated selectively by a mirror.

Deep Space Network (DSN) Enhancement Project



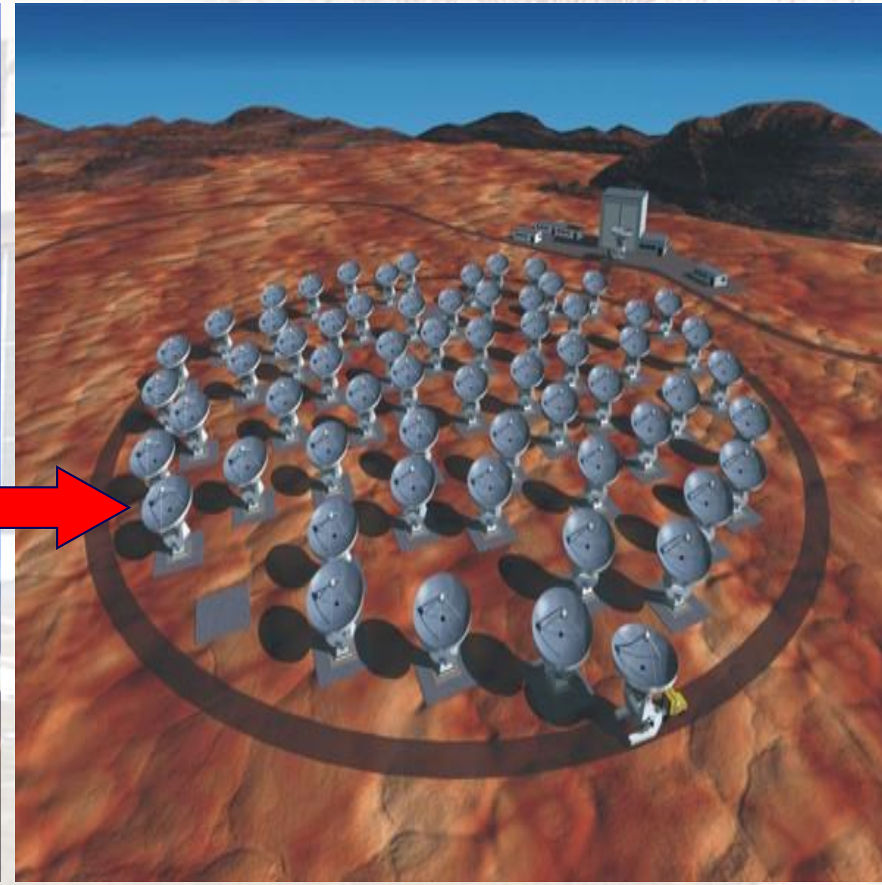
DSN Configuration: 2025

By 2025, the 70 meter antennas at all three locations will be decommissioned and replenished with 34 meter BWG antennas that will be arrayed.

All systems will be upgraded to have X-band uplink capabilities and both X- and Ka-band downlink capabilities.

Trend for Next Generation DSN

Single Large Aperture Antenna



Smaller Aperture Antenna Array

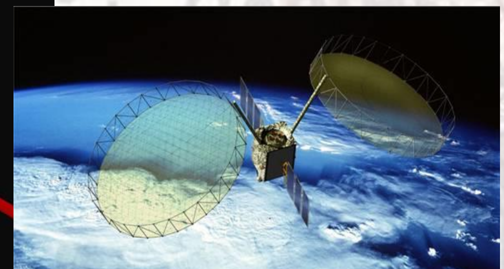
Enabling Technologies for Space Communications

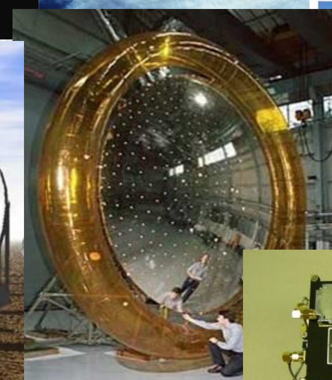
Optical Communications

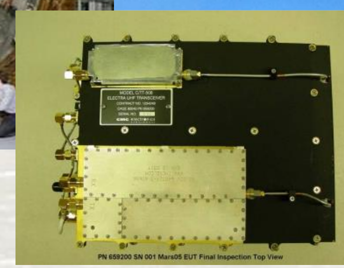
- High capacity comm with low mass/power required
- Significantly increase data rates for deep space
- LLCD (October 2013; 622 Mbps Moon to Earth Surface)*
- Other efforts (LCRD, DSOC, iROC being developed)

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

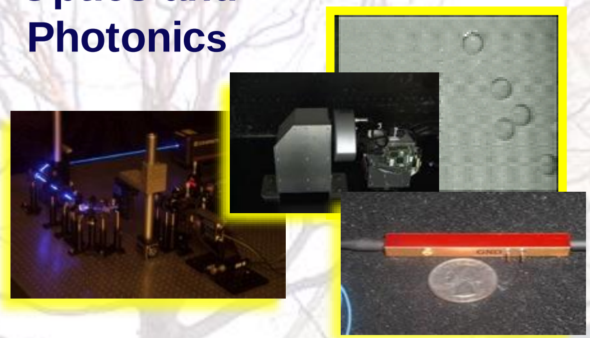
Software Defined Radio/Cognitive Systems

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

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

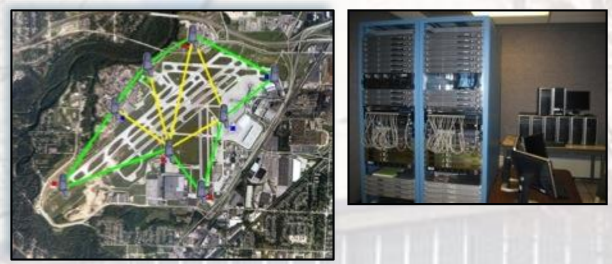
Communications and Intelligent Systems

Optics and Photonics



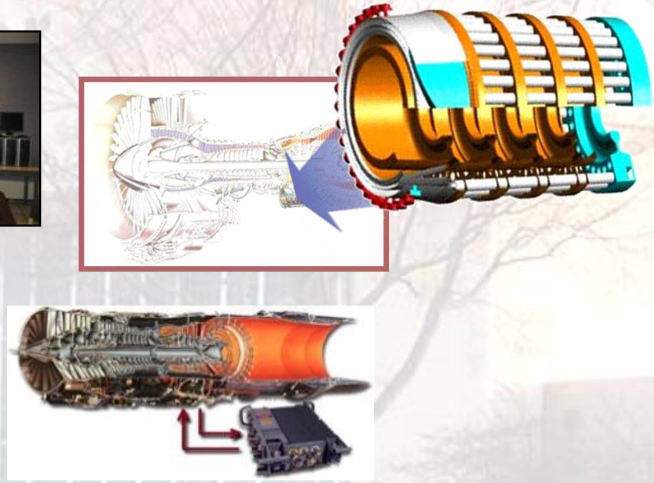
Optical Instrumentation
Optical Communications
Health Monitoring

Architectures, Networks and Systems Integration

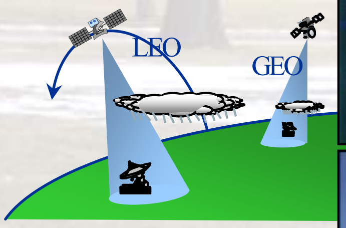


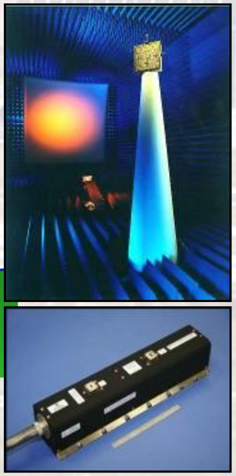
Communications Architectures
Modeling and Simulation/Tech Demos
Spectrum and Link Analysis

Intelligent Control and Autonomy



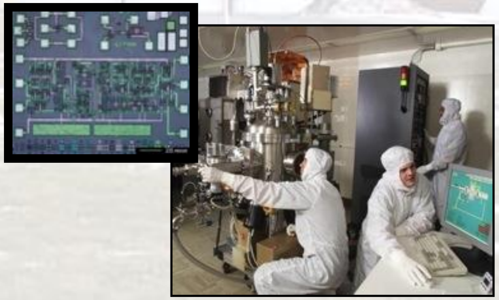
Advanced High Frequency





Antennas/Propagation
RF Systems and Components
3-D Electromagnetic Modeling

Smart Sensors and Electronics Systems



Thin Film Physical Sensors
High Temp/Harsh Environment Focus
Wireless Technologies

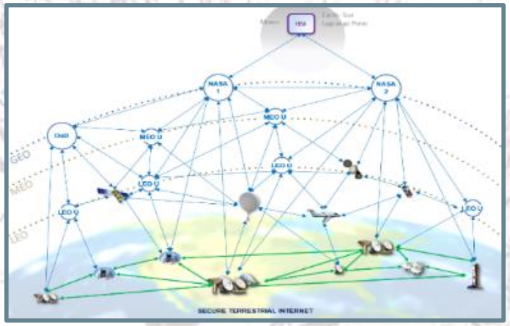
Information and Signal Processing

Radio Systems – SDRs, Cognitive
Bandwidth and Power-Efficiency
Waveform Development

Advanced High Frequency R&D and Technology Development

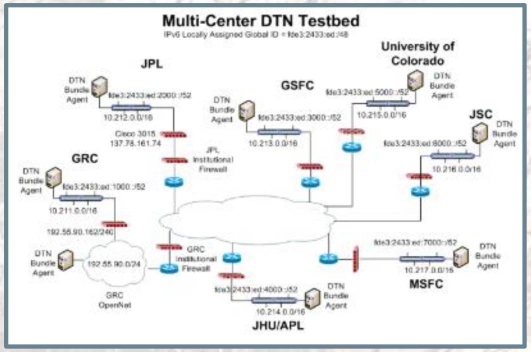
- Conducts research and technology development, integration, validation, and verification at frequencies extending up to the terahertz region in the areas of semiconductor devices and integrated circuits, antennas, power combiners, frequency and phase agile devices for phased arrays, and radio wave propagation through Earth's atmosphere, in support of NASA space missions and aeronautics applications.
- R&D is conducted in-house and also in collaboration with academia and industry to develop low mass, small size, high power and efficiency traveling-wave tube amplifiers, solid state power amplifiers; novel antenna technologies (e.g., wideband antennas, hybrid antennas (i.e., RF/Optical), ground stations, among others.
- Supports development of advanced technologies such as superconducting quantum interference filter (SQIF) for ultra-sensitive receivers and Ka-band multi-access arrays for NASA's next generation space communications.
- Facilities include planar and cylindrical near-field, far-field and compact antenna ranges, cryogenic microwave and millimeter-wave device and circuit characterization laboratory, high power amplifier characterization laboratory, radio wave propagation laboratory, and clean room facilities.
- Semiconductor device modeling and high frequency circuit simulation, fabrication, and integration facilities are also available.
- Unique expertise and critical mass in Analog Electronics for technology integration in support of aerospace projects.

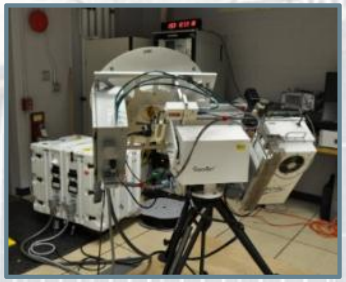
Architectures, Networks and Systems Integration

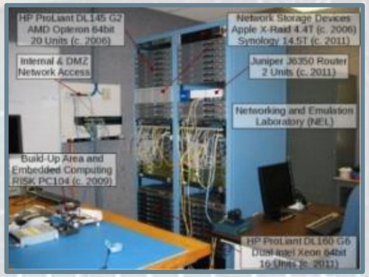


Communications Systems

- Systems engineering of future SCaN Integrated Network Architecture.
- Requirements decomposition, systems definition, development, hardware and software build up, test and delivery of Space Network compatibility test unit including TDRS signal simulator.

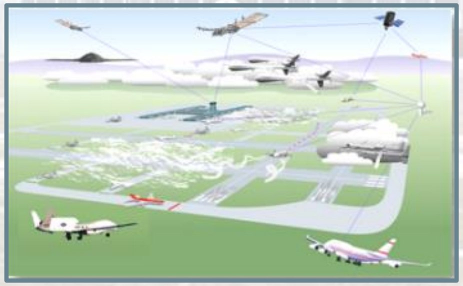






Aeronautical Communications

- Includes air-to-air, air-to-ground, and ground-based mobile wireless communications, information networking, navigation and surveillance research, technology development, testing and demonstration, advanced concepts and architectures development, and national and international technology standards development.



Network Research

- Development of network components, design of network layers and networked systems architectures. Emphasis is on secure wireless mobility, protocol characterization and development, requirements definition, and flight software/hardware component assessment. Also includes "virtual" mission operations.

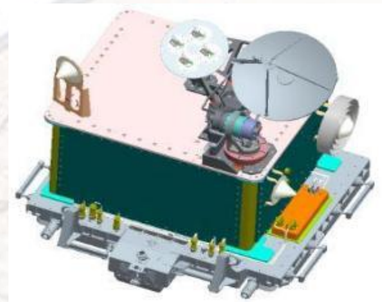
Information and Signal Processing

LCI Overview

Conducts research and technology development of information and signal processing methods and approaches of digital communications systems for aerospace applications. Emphasis on software-defined and cognitive radios; open SDR architectures and waveform development; position, navigation and timing methods; spectrum and power efficient techniques; reconfigurable microelectronic devices

Focus Areas

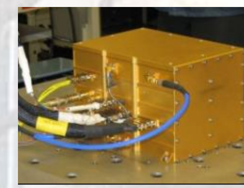
- Software-Defined and Cognitive Radios
  - Space Telecommunications Radio System (STRS)
  - STRS-compliant Hardware and Software
  - SDR Waveform Development
  - Digital Core for RF/Optical Terminal
- High Speed Signal Processing
  - Computer Modeling and Simulation Tools
  - Wireless and Microelectronic Devices for Communications
- Advanced Exploration Systems
  - Integrated Audio/Microphone Arraying
  - EVA Radio Development
  - Surface Navigation
- SCaN Testbed Flight Radio Experiments and Demonstrations
  - GPS Navigation and Timing
  - Ka-Band, Bandwidth-Efficient, High Rate Waveform
  - S- and Ka-Band IP Networking and Routing
  - Adaptive Modulation and Coding for Cognitive Radio



SCaN Testbed

Facilities/Labs

- Software-Defined and Cognitive Radio Technology Development Laboratory
- Digital Systems and Signal Processing Lab
- EVA Radio and Integrated Audio Lab
- SCaN Testbed on ISS Available for Experimenters



Software Defined Radios

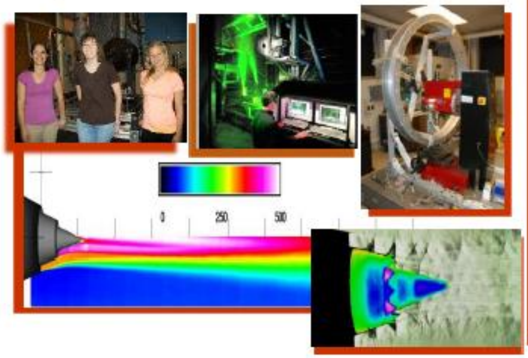
Extra-Vehicular Activity (EVA) Radio

AES/EVA Integrated Audio

iROC Flexible Digital Co

Optics and Photonics

Optical Instrumentation



http://www.grc.nasa.gov/WWW/Optinstr/

- Our data and instrumentation help designers understand the fundamental physics of new systems, validate aeronautics computational and life models, and improve space optical communications for human and robotic explorations.
- Our data leads to improved designs, validation and verification of systems performances, increased communications, safety and security and reduced design cycle times for many of the core technologies developed at Glenn and across NASA.

Flow/Noise Diagnostics
- Particle imaging Velocimetry (PIV)
- Background Oriented Schlieren
- Rayleigh Scattering
- PIV Tomography
- Combustion diagnostics
- Raman Diagnostics (Species, T)
- Plasma generation

Surface Diagnostics
- Temperature Sensitive Paint
- Pressure Sensitive Paint
- Stress Sensitive Film

Engine Icing
- Light Extinction Tomography
- Light Extinction Probes
- Raman Spectroscopy
- Impedance Sensor

Optical Communications

Free Space Communications
- Optical Teletennas
- Beaconless Pointing Systems
- High Data Rate for Deep Space & Near Earth

Secure Quantum Communications
- Quantum Entanglement
- Pulsed photon Pairs
- Quantum Illumination
- Quantum Key Distributions

Photonics and Health Monitoring

Mobile and Remote Sensing
- On-Orbit Solar Cell Characterization MISSE 5-8; TACSAT- 4;
- Hyperspectral Imaging
- Mobile Sensing Platforms

Communications
- Communications over power lines
- Communications Interface Boards
- High Data Rate

Health Monitoring
- Microwave Blade Tip Clearance
- Self diagnostic Accelerometer
- Fiber optics sensors
- Morphology dependent resonance
- Phosphor Thermography
- Capacitance & piezo patches sensors
- Wireless and wired techniques

Smart Sensors and Electronics Systems

Description

Conducts research and development of adaptable instrumentation to enable intelligent measurement systems for ongoing and future aerospace propulsion and space exploration programs. Emphasis is on smart sensors and electronics systems for diagnostic engine health monitoring, controls, safety, security, surveillance, and biomedical applications; often for high temperature/harsh environments.

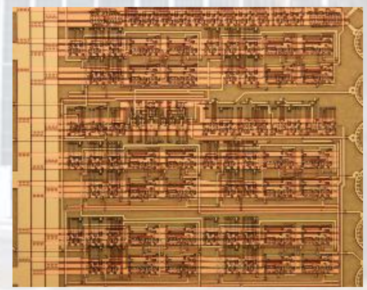
Microsystems Fabrication Facility

Facilities/Labs

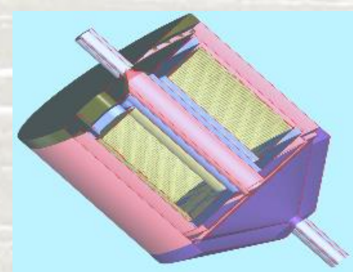
- Microsystems Fabrication Facilities
  - Class 100 Clean Room
  - Class 1000 Clean Room
- Chemical vapor deposition laboratories
- Chemical sensor testing laboratories
- Harsh environment laboratories
  - Nanostructure fabrication and analysis
  - Sensor and electronic device test and evaluation

Focus Areas

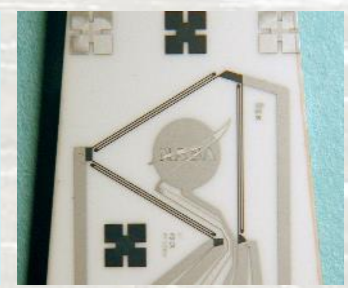
- Silicon Carbide (SiC) - based electronic devices
  - Sensors and electronics for high temp (600°C) use
  - Wireless sensor technologies, integrated circuits, and packaging
- Micro-Electro-Mechanical Systems (MEMS)
  - Pressure, acceleration, fuel actuation, and deep etching
- Chemical gas species sensors
  - Leak detection, emission, fire and environmental, and human health monitoring
- Microfabricated thin-film physical sensors
  - Temperature, strain, heat flux, flow, and radiation measurements
- Harsh environment nanotechnology
  - Nano-based processing using microfabrication techniques
  - Smart memory alloys and ultra low power devices



SiC Signal Processing



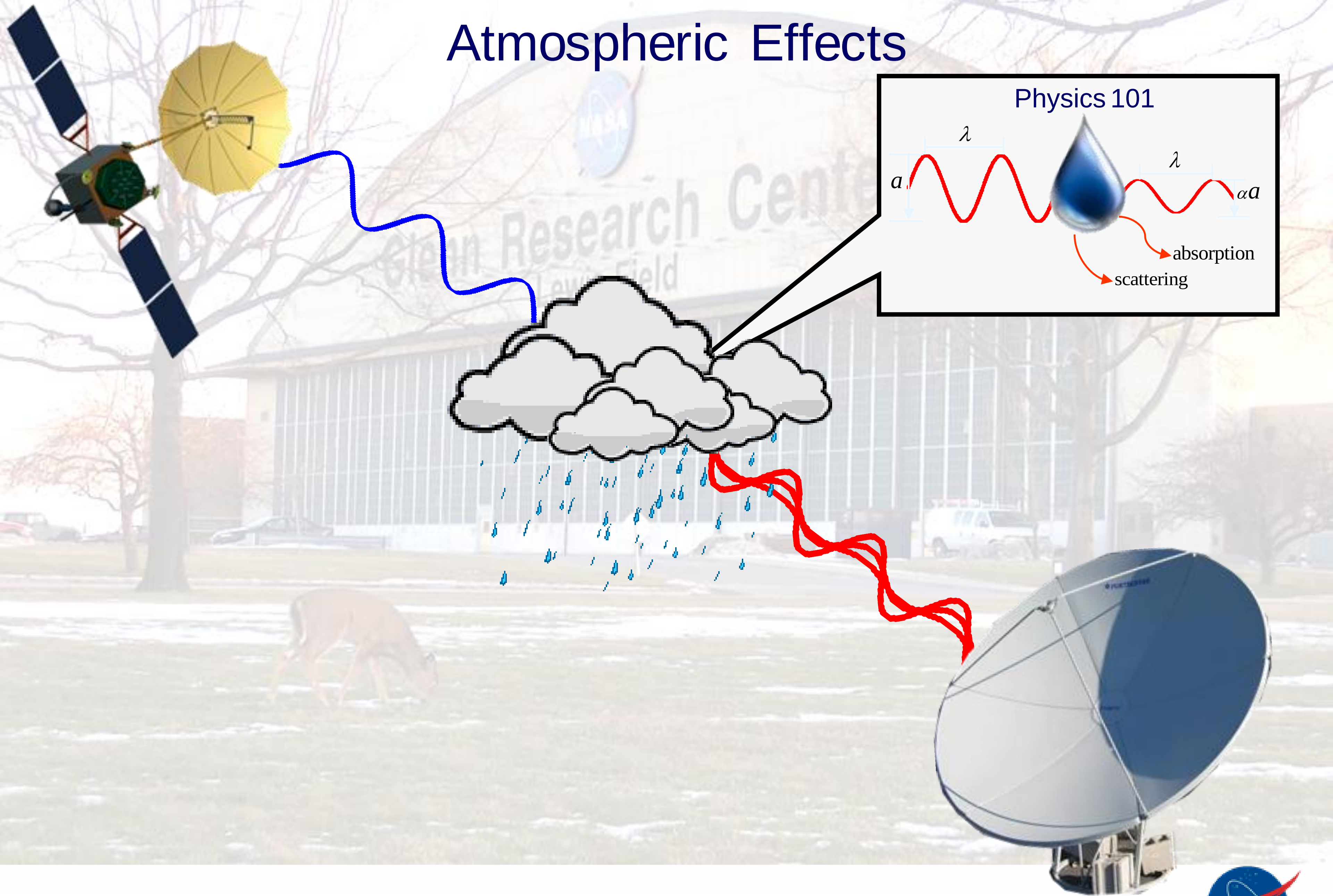
MEMS Fuel Actuation



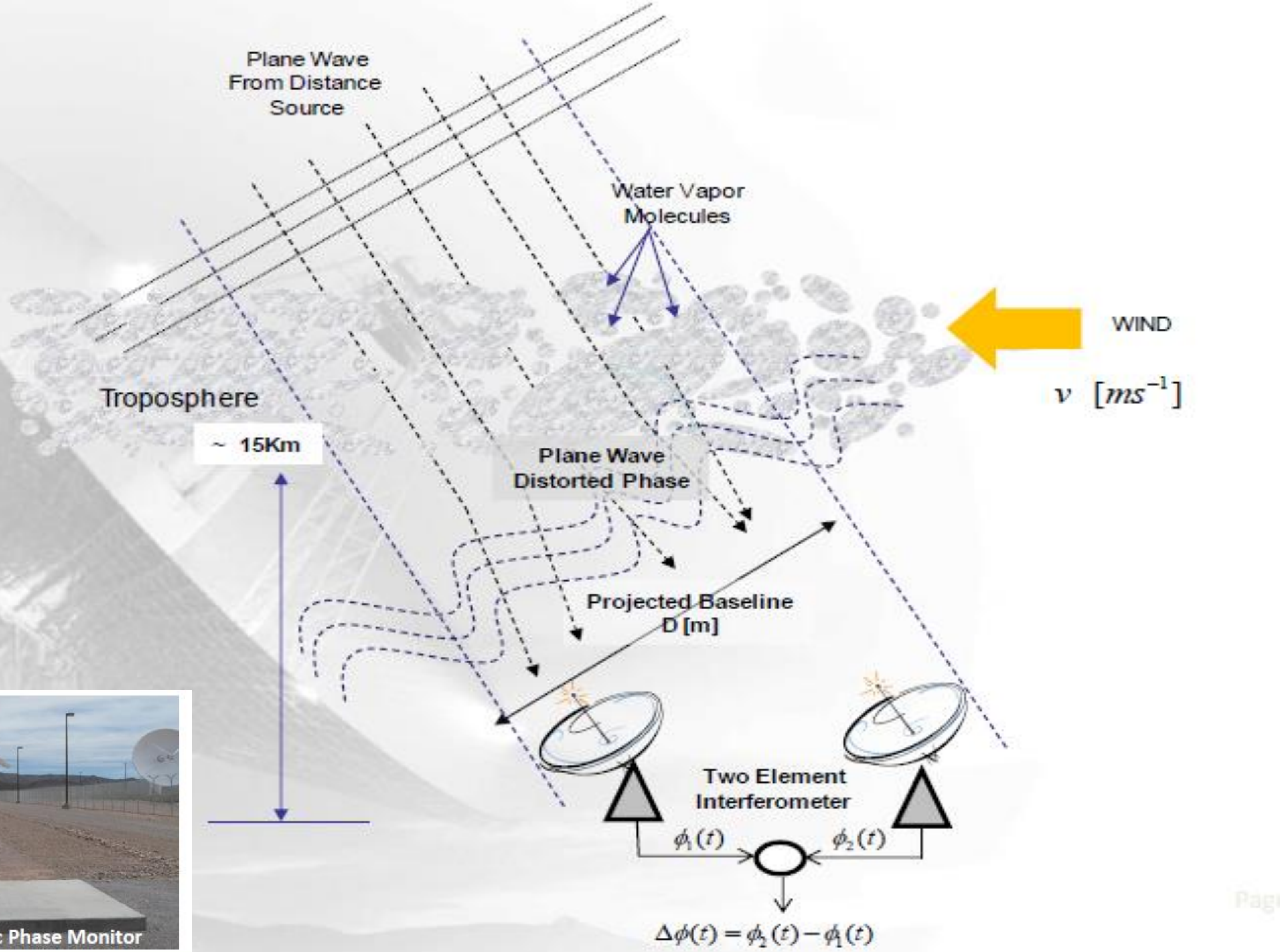
Thin Film Physical Sensors

RF Propagation

Atmospheric Effects

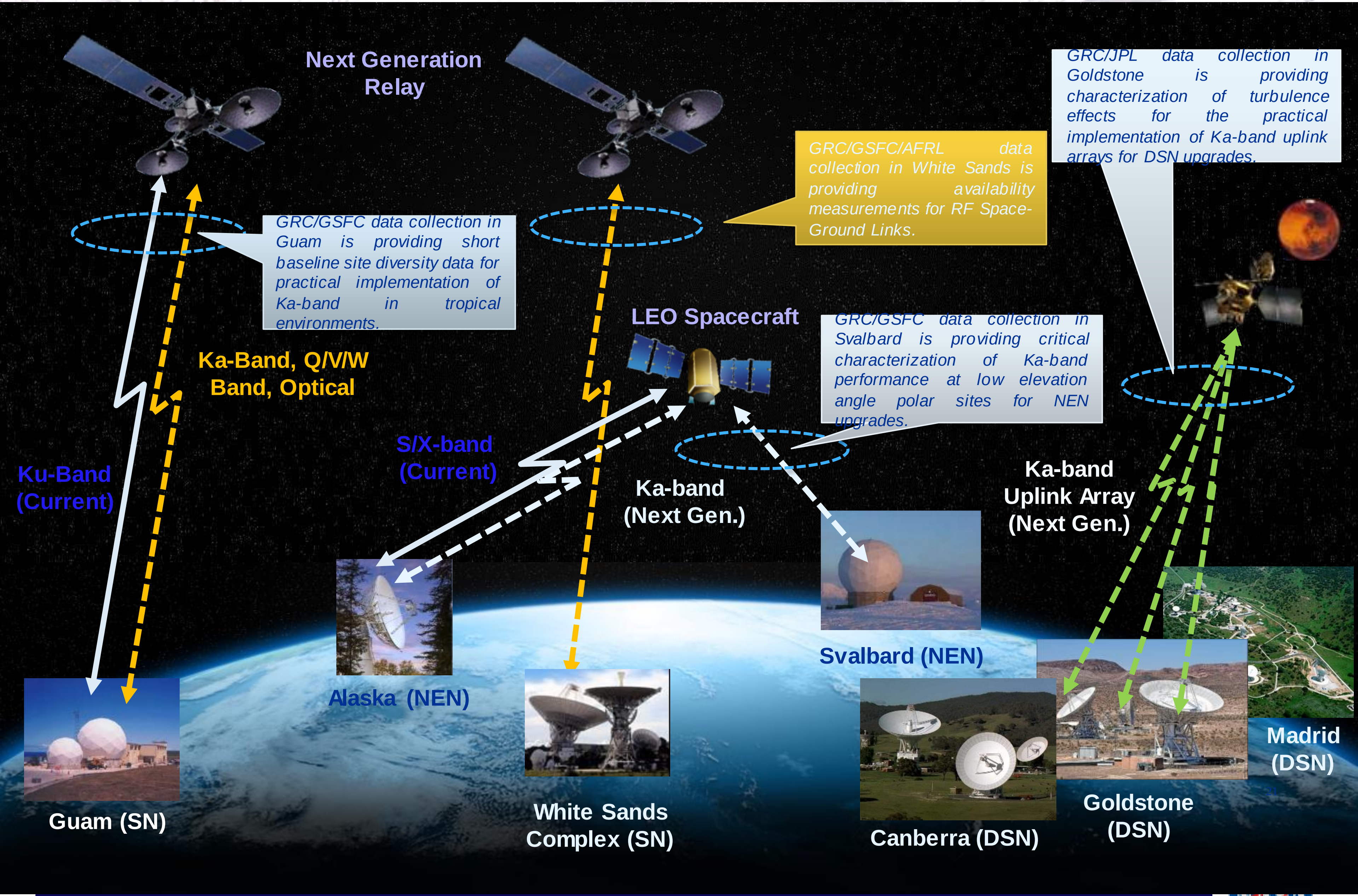


Problem Statement



GRC Product: Atmospheric Phase Monitor

Propagation Studies Relevance and Impact



Current NASA Network Characterization Sites

In the post-ACTS era, NASA propagation activities have primarily focused on site characterization of NASA operational networks throughout the world.

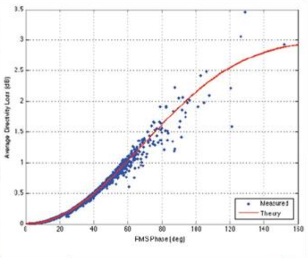
RF Propagation – The Road From Idea to Deployment

mm-wave Propagation Studies: 2012-Future

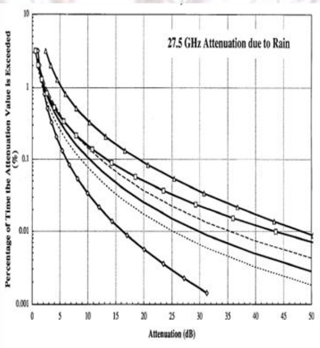
GRC undertakes expansion of mm-wave frontier via propagation activities in the Q/V/W bands

Q-band Radiometer

mmWave Propagation



Phase measurements implemented in array loss predictions



ACTS Propagation Data instrumental in development of ITU-R attenuation models

Guam (SN)

Svalbard (NEN)

Evolution of GRC Propagation Terminals

White Sands, NM (SN)

Goldstone, CA (DSN)

Real-Time Compensation: 2012-2016

SCaN funded effort to integrate real-time compensation techniques into NASA network operations

ACTS Propagation Terminal

Atmospheric Phase Studies: 2004 – Present

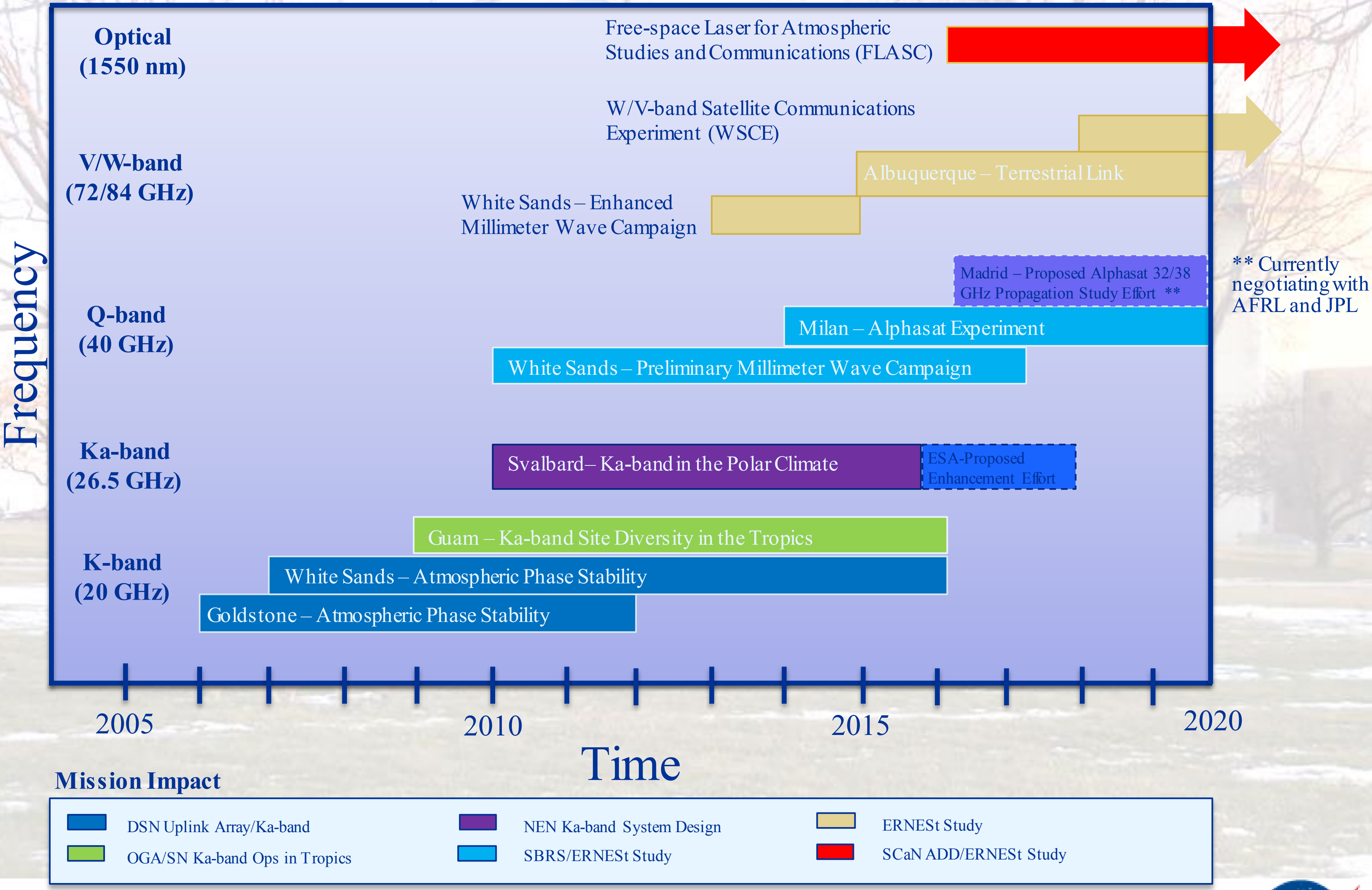
Characterization of atmospheric phase noise is studied to identify suitable sites for Uplink Arraying Solution to large aperture 70-m class antenna issues with Deep Space Network. GRC, in collaboration with JPL and GSFC, leads the characterization of atmospheric-induced phase fluctuations for future ground-based arraying architecture

ACTS Satellite

Atmospheric Attenuation Studies: 1993 – 2002

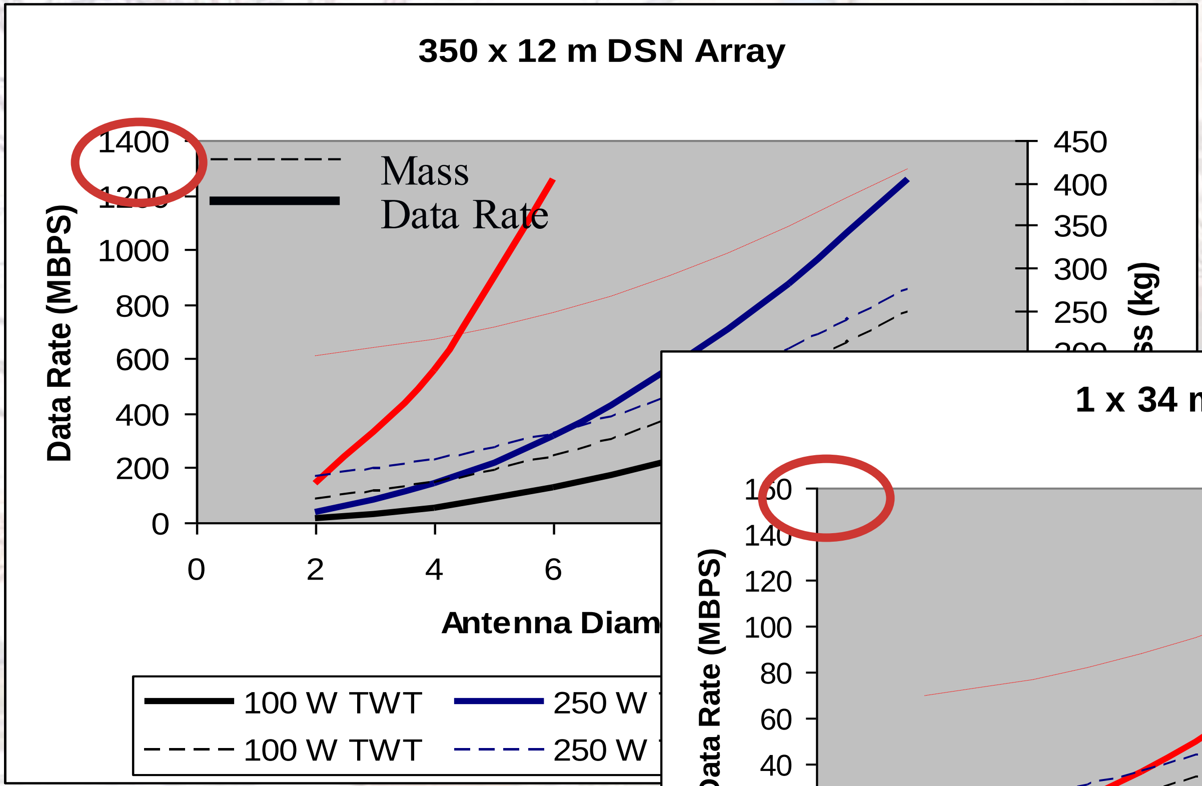
Propagation studies were undertaken by NASA to determine the effects of atmospheric components (e.g., gaseous absorption, clouds, rain, etc.) on the performance of space communication links operating in the Ka-band. Sites throughout the Continental US and Puerto Rico were characterized.

Evolution of Propagation Studies Task

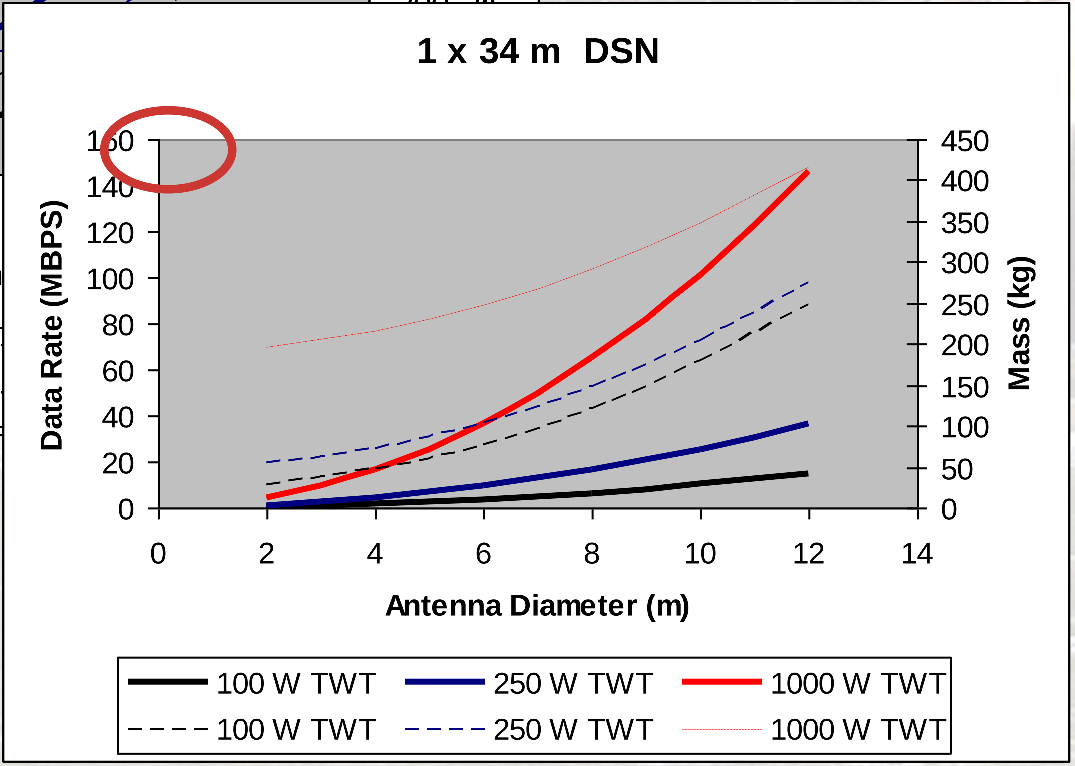


Large Aperture Deployable Antennas

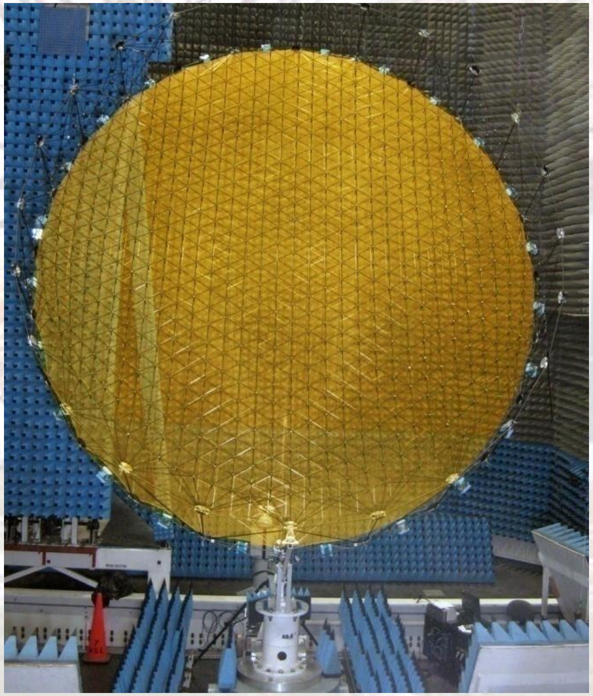
Rationale For Large Deployable Antennas



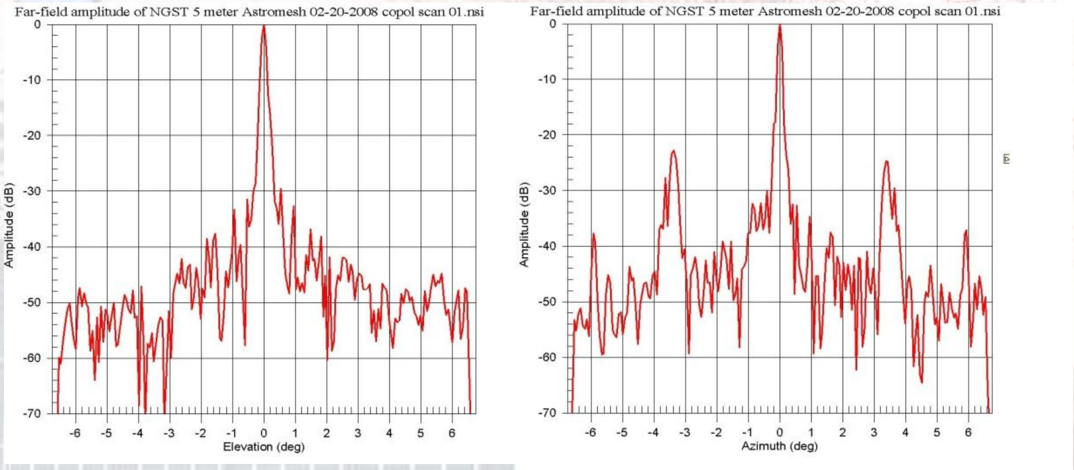
Corresponding Ka SC Power:
183 W
550 W
2444 W



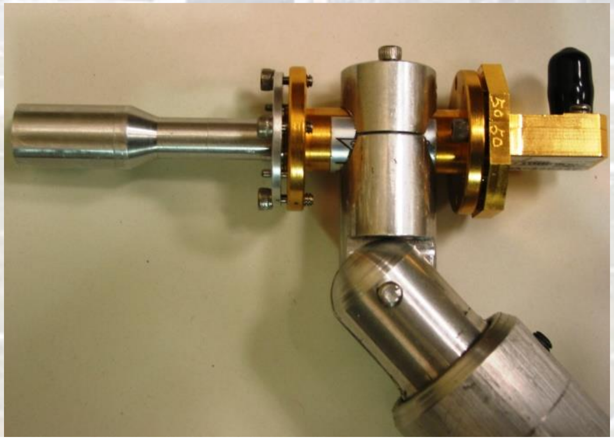
NGST 5m Astromesh Reflector Evaluated at 32, 38 and 49 GHz as well as laser radar surface accuracy mapping



NGST 5 m “Astromesh” Reflector
in NASA GRC Near-Field Range



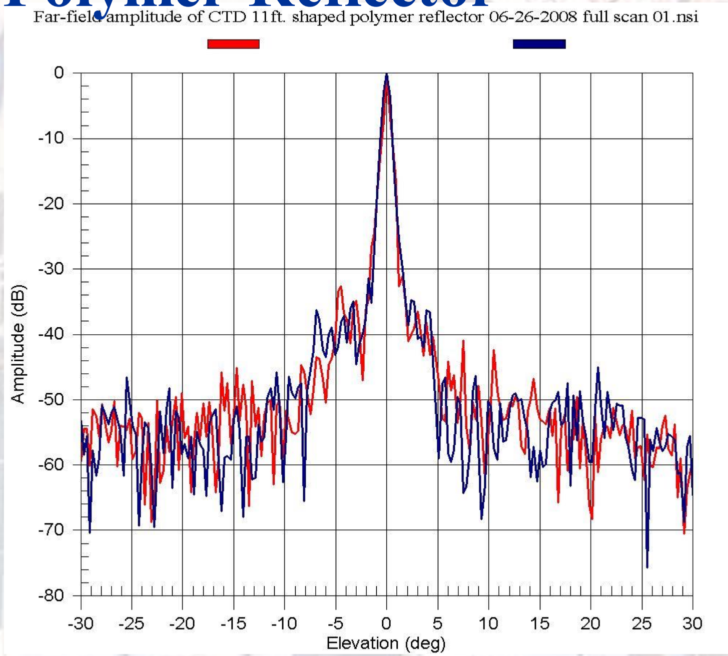
Far Field Elevation and Azimuth pattern at 33 GHz
(Directivity = 62.8 dB)



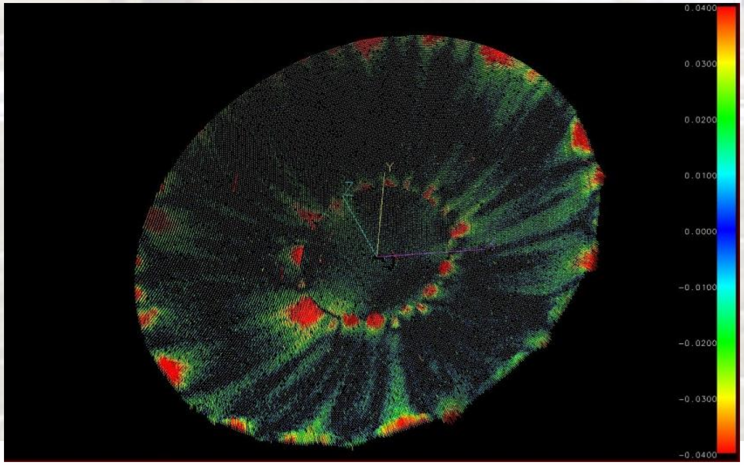
GRC Dual-band feed horn assembly

Composite Technology Development
Shape Memory Polymer Reflector

3.2 m Shape memory Polymer Composite Reflector



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

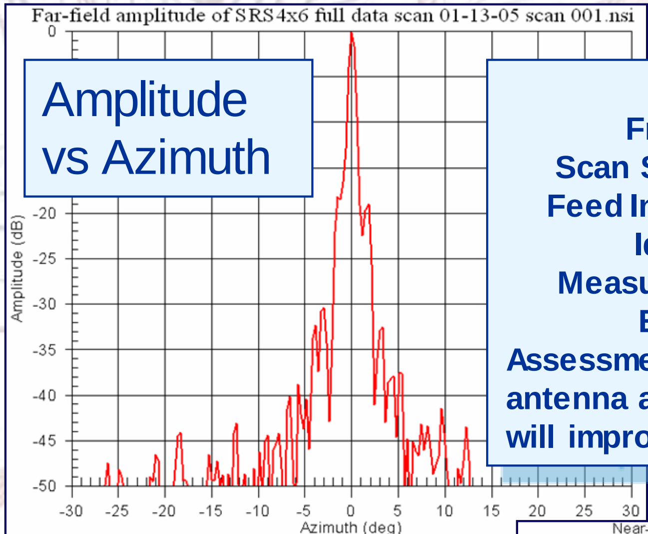


Surface metrology based on laser radar scan. RMS error=0.014”

Stowed Configuration

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

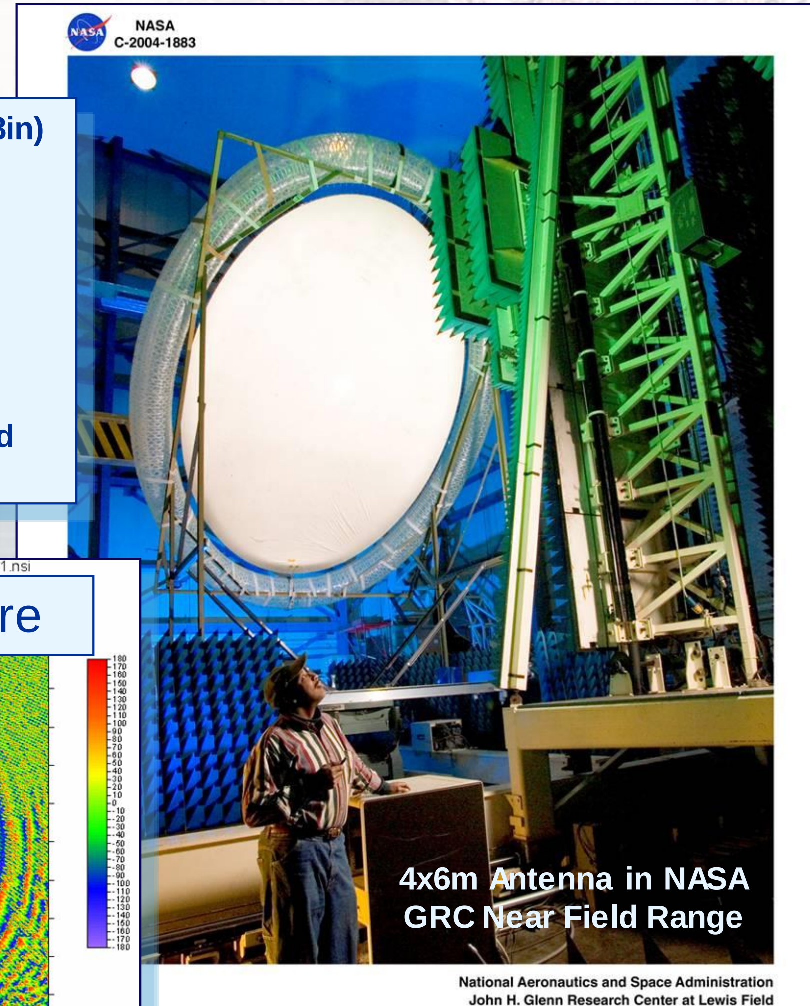
4x6m Antenna RF Characterization



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%

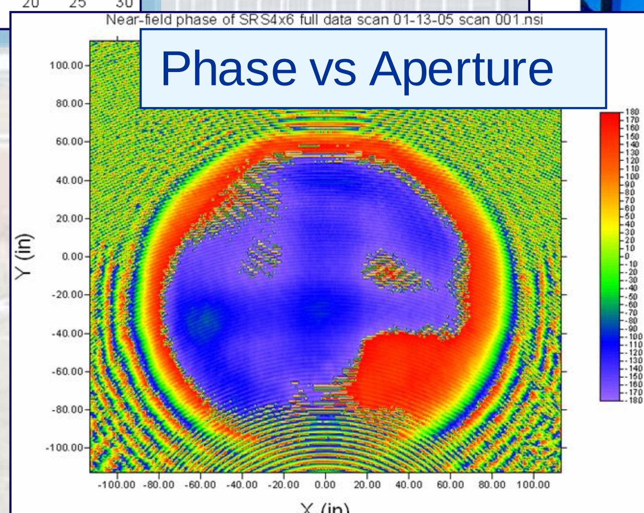
Assessment: Performs well as antenna at X-band. Optimized feed will improve performance.



4x6m Antenna in NASA GRC Near Field Range

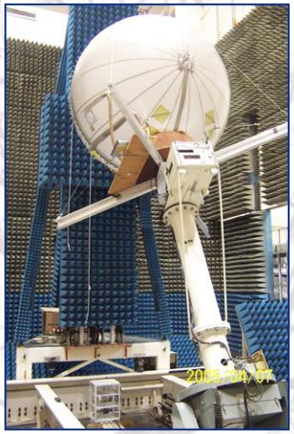
Design Specs

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



Phase vs Aperture

Large Aperture Deployable Antennas



Prototype Inflatable Radome Antenna System at GRC

In The Field: 2009-2010

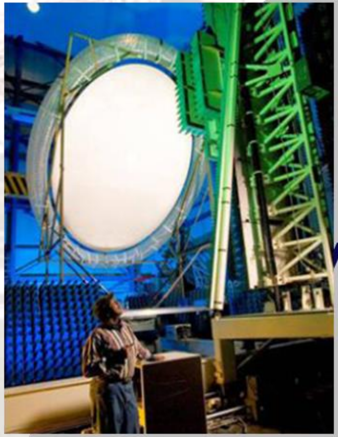
Popular Science's – Invention of the Year 2007, listed as one of the "Inc. 500: The Hottest Products" of 2009. GATR continues to field units which enable high-bandwidth Internet, phone and data access for deployments and projects in Afghanistan, South Africa, South America, Haiti, Korea, as well as assisting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

GPS GND Terminals: 2014

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

0.3 meter prototype Membrane reflector

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.

Seedling Idea: 2004

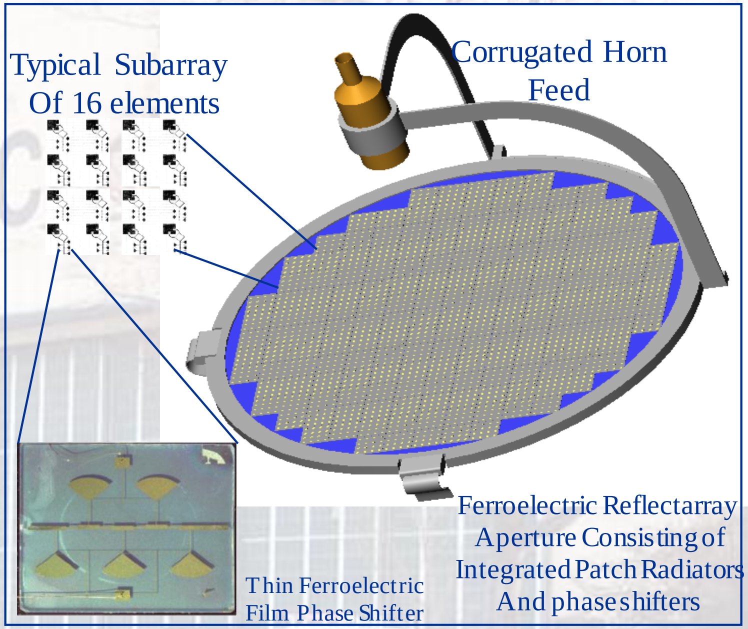
Circa 2004 need for large aperture deployable antenna identified for JIMO and Mars Areostationary relay platform. Antenna technology adapted from 1998 Phase II SBIR solar concentrator project.

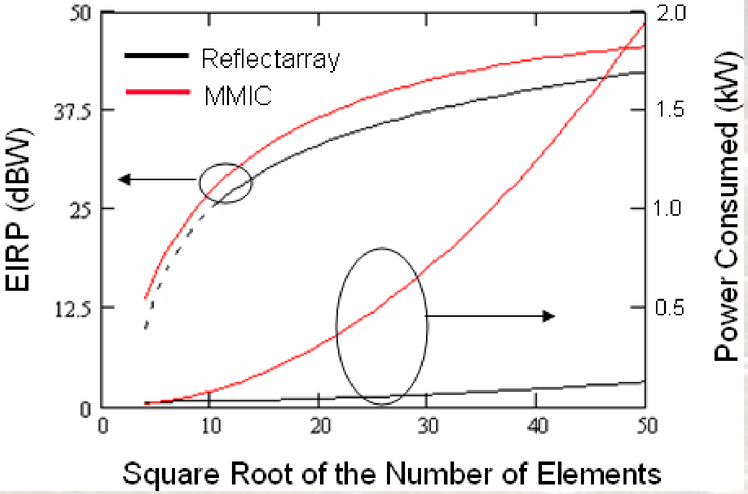
Reflectarray Array Antenna

Low Cost, High Efficiency Ferroelectric Reflectarray

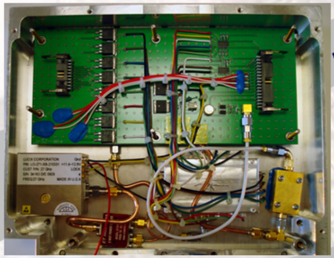
Technology Description:

- 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



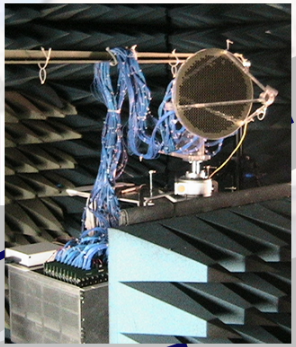
MISSE-8 ISS Space Exp.; STS-134 ,05/16/ 2011. Returned to Earth 07/2014

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

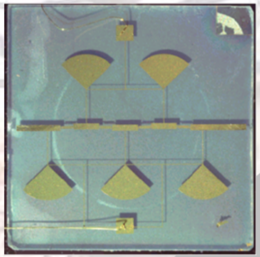
R&D 100 Award Winner

2010



Cellular Reflectarray: 2010

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



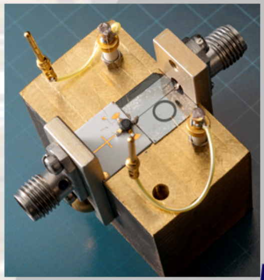
Thin film ferroelectric phase shifter on Magnesium Oxide

Practical Phase Shifters : 2003-2004

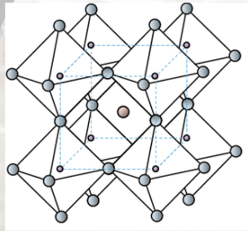
Novel phased array concept based on quasi-optical feed and low-loss ferroelectric phase shifters refined. 50 wafers of $Ba_{0.5}Sr_{0.5}TiO_3$ on lanthanum aluminate processed to yield over 1000 ferroelectric K-band phase shifters. Radiation tests show devices inherently rad hard in addition to other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

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



First Ku-Band tunable Oscillator based on thin ferroelectric films



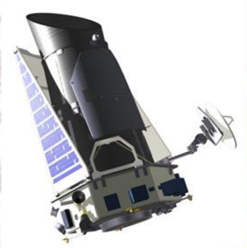
Parent crystal: Strontium Titanate

Seedling Idea: 1995-1999

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

Power Amplifiers

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



LRO TWTA

SCaN Testbed TWTA

High Throughput

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*

100 Watt TWT

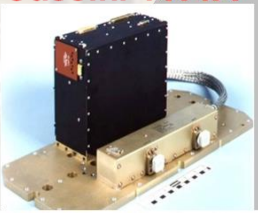
Jupiter Mission – Higher FoM: 2004-2006

- *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

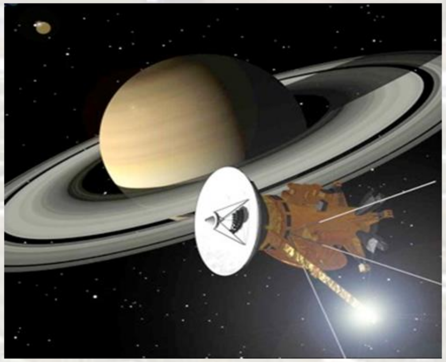
- *Demonstrated a Ka-Band space TWT, output power 100 W, efficiency 60 %, mass 2.3 kg. Output power 10X higher than the Cassini TWT and FoM is 43*

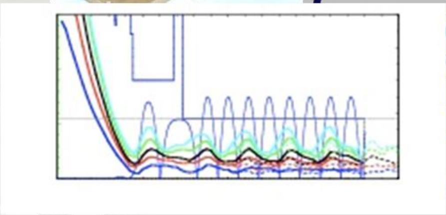
Cassini TWTA



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*



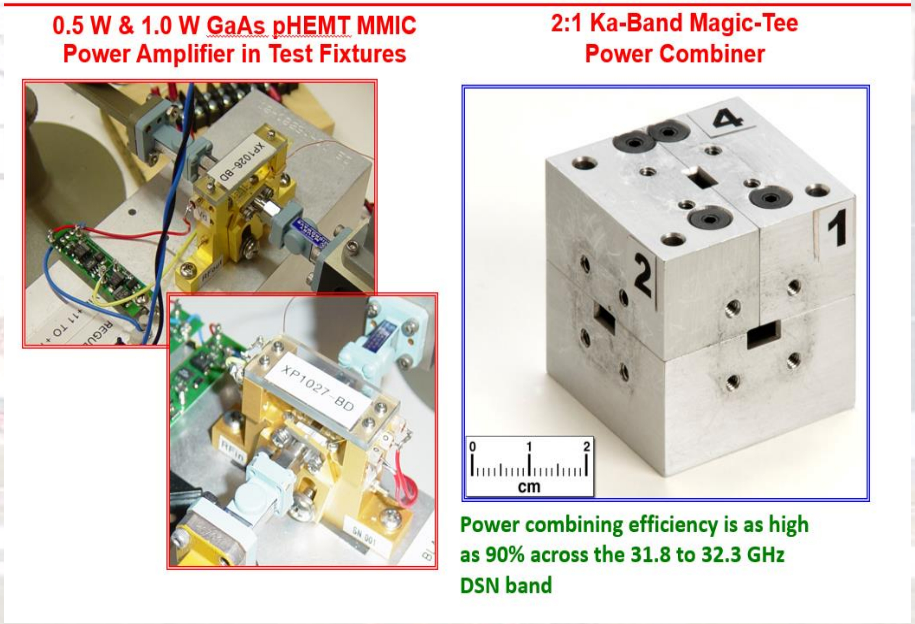


Modeling & Simulations: 1980-1995

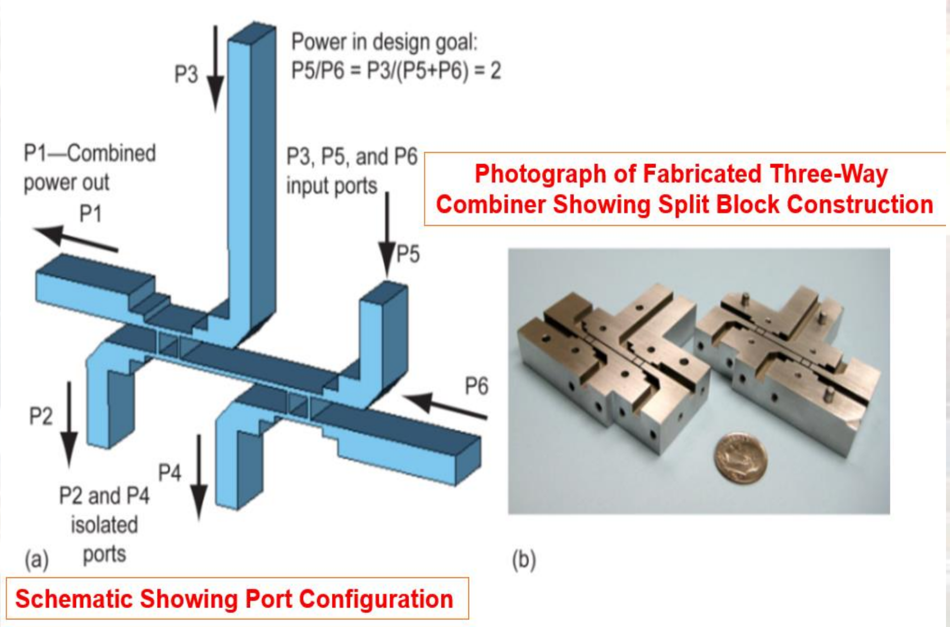
- *Basic design studies on traveling-wave tube (TWT) slow wave interaction circuits, collector circuit, focusing structure, electron gun and cathode*

Hybrid Power Combiner for Ka-Band SSPA

Magic-Tee Power Combiner for Ka-Band SSPA



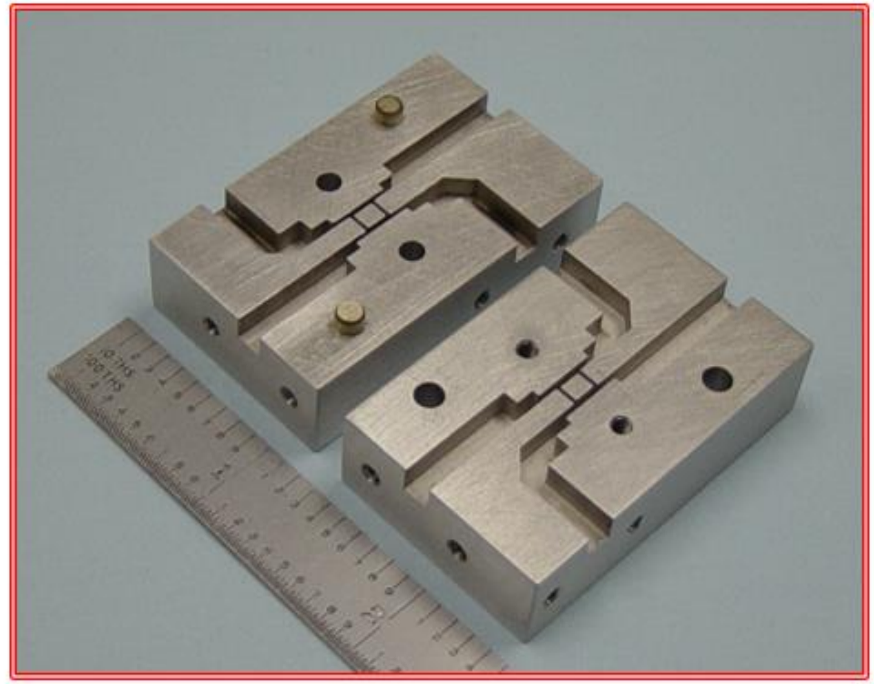
Three-Way Branch-Line Serial Combiner for Ka-Band SSPA



Hybrid Power Combiner for Ka-Band SSPA

Experimental Set-Up for Demonstrating Power Combining

2:1 Ka-Band Branch-Line Hybrid Power Combiner

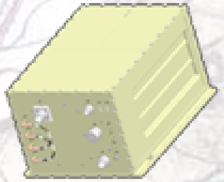


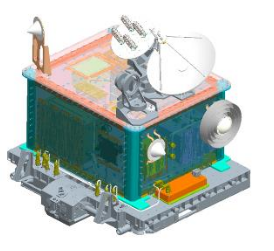
Power combining efficiency is as high as 92% across the 31.8 to 32.3 GHz DSN band

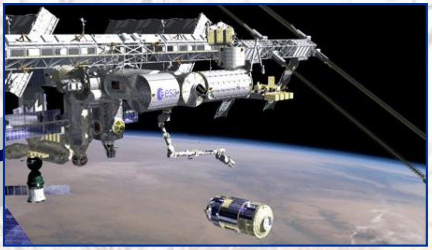
Software Defined Radios-STRS Architectures

Software Defined Radios-STRS Architectures

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



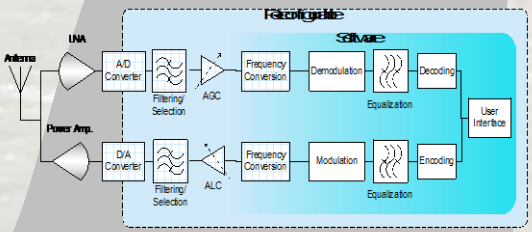




Technology Experiments: 2013 – 2017

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.

Space Communications and Navigation Experiments on ISS

Overview

Revolutionary approach to develop and operate communication radios

Software defined radios with communications and navigation functions implemented in software provide the capability to change the functionality of a radio during mission development or after launch

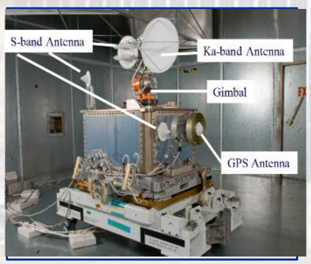
Cognitive radios are software defined radios whose applications learn their signal environment and makes decisions based on its circumstances

SCaN Testbed available for experiments

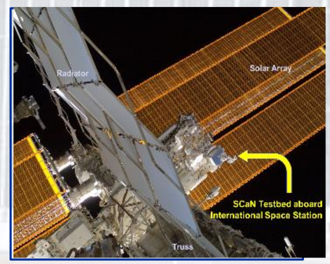
Benefits

•Changing the operating characteristics of a radio through software, once deployed to space, offers the flexibility to adapt to new science opportunities, increase data return to Earth, recover from anomalies within the satellite, and potentially reduce development cost and risk by using the same hardware platform for different missions and using software to meet specific mission requirements

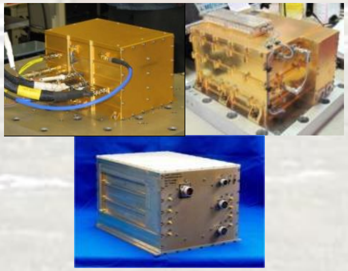
•Advances the readiness of SDR technology for adoption by future space missions



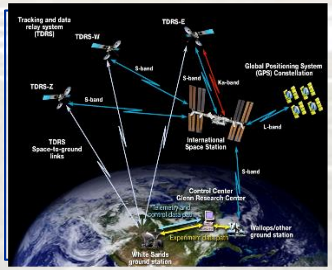
SCaN Testbed Flight System, Pre-Launch



SCaN Testbed on ISS



Software Defined Radios; Harris Corp, General Dynamics Corp., JPL



SCaN Testbed System Overview

Applications

• Reprogrammable radios adapt to changing mission requirements during development through software/firmware changes mitigating schedule impacts.

•SDR can be used to mitigate failures and use all available communication link margin in flight to obtain greater science data return for missions.

•STRS-compliant software defined functionality tailored for specific missions with reusable software. Provide reusable waveforms and software components saving development time and cost

How it works

Signal processing hardware called Field Programmable Gate Arrays run software-like code called firmware, especially designed for space environment

Mission designers write firmware to run on the radios that create, transmit, receive, and process signals to meet mission needs

From the Control Center, satellite operators send new firmware to the satellite radio's FPGAs to change the radio functionality

Why it is better

Cognitive and SDRs adapt to the environment and mission needs through firmware and software changes providing more science return, and reducing cost and schedule impact to missions

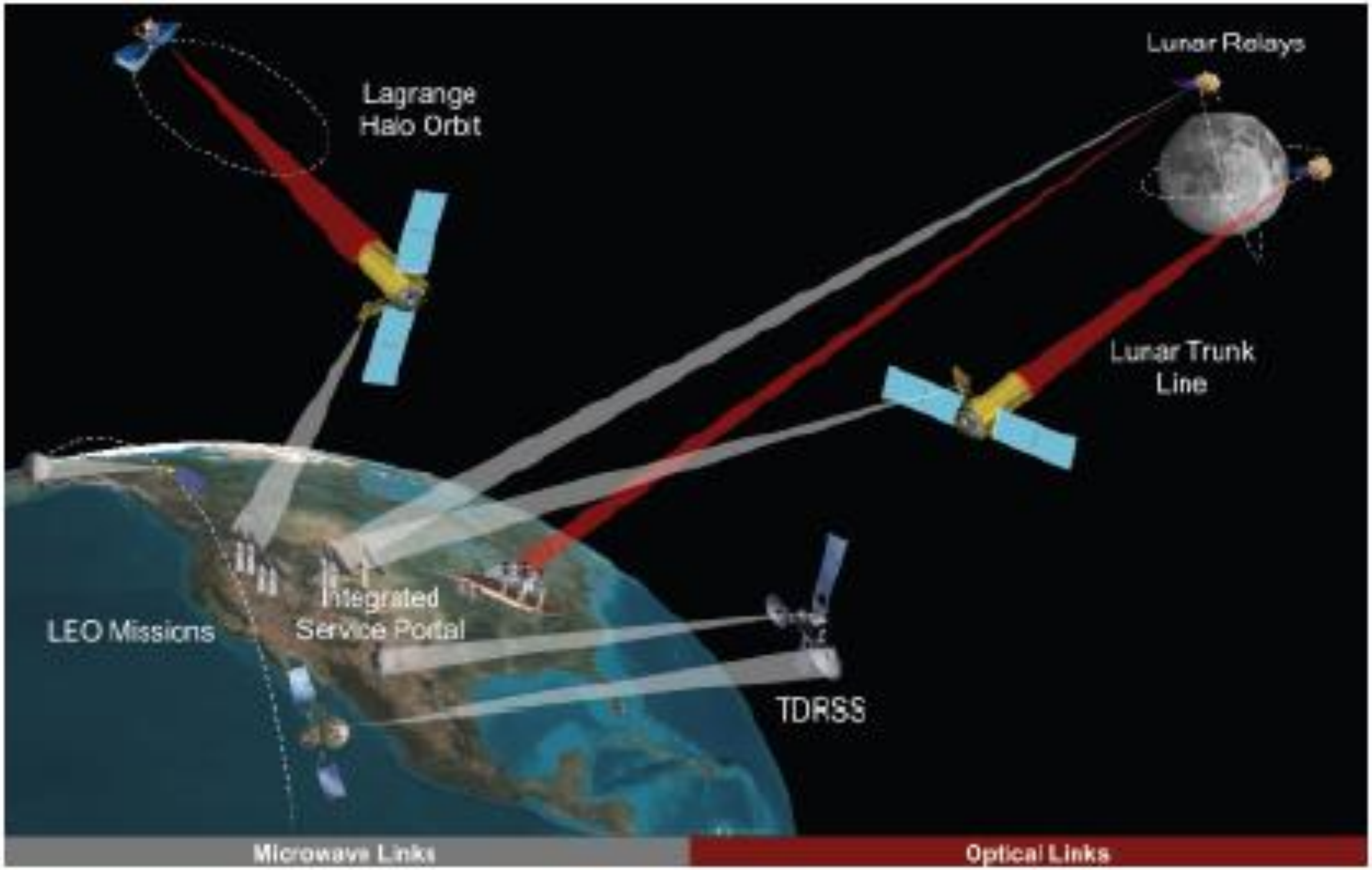
NASA's new common Architecture, Space Telecommunications Radio System, enables application developers independent of the platform developer, new for NASA and SDR developers.

SCaN Testbed is NASA's first space user of new frequency band, Ka-band, opening new frequencies to missions and first in-space reception and analysis of new GPS "L5" frequency, enabling greater position accuracy for spacecrafts

Optical Communications

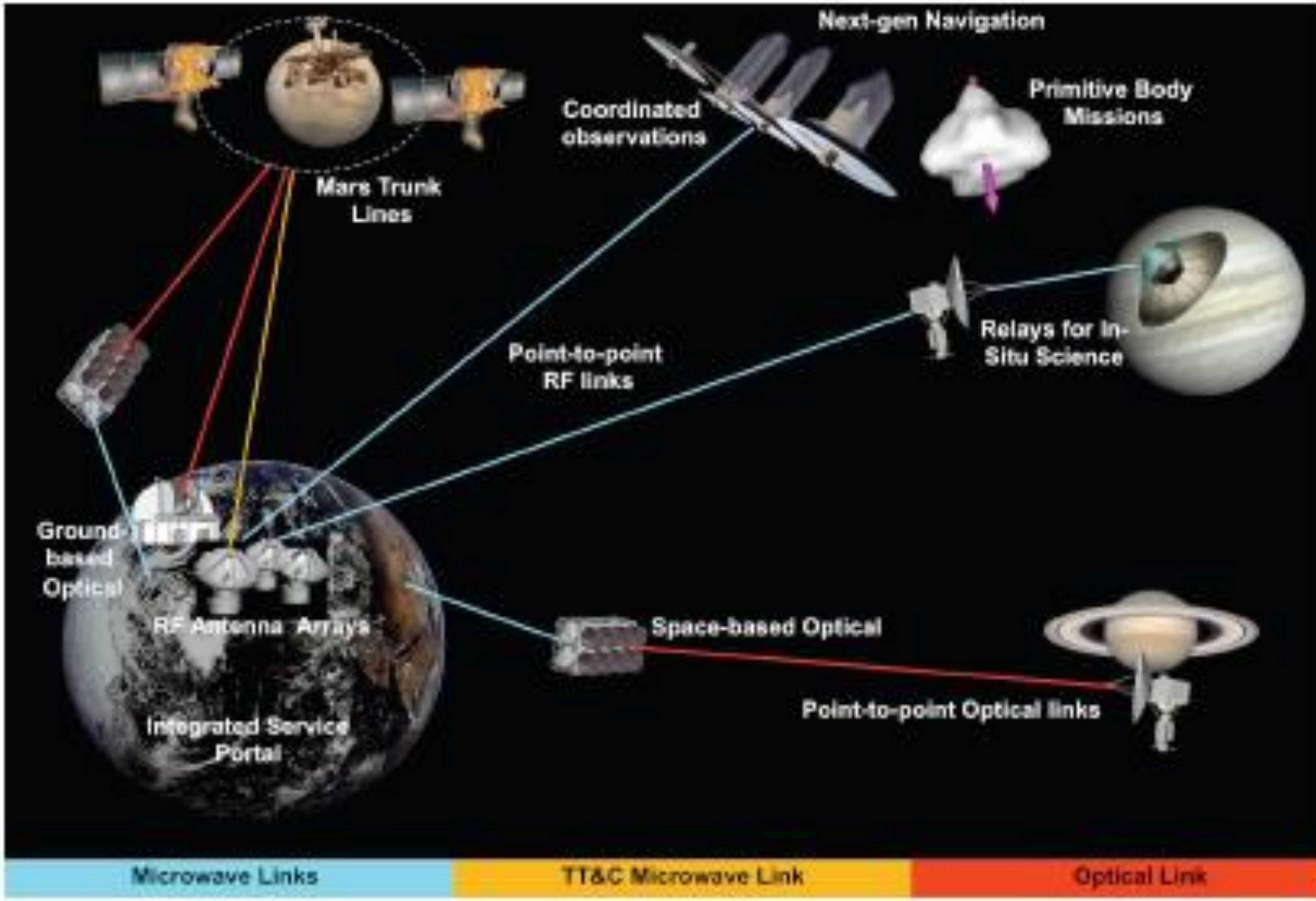
Optical Communications

Near Earth Domain



Optical Communications

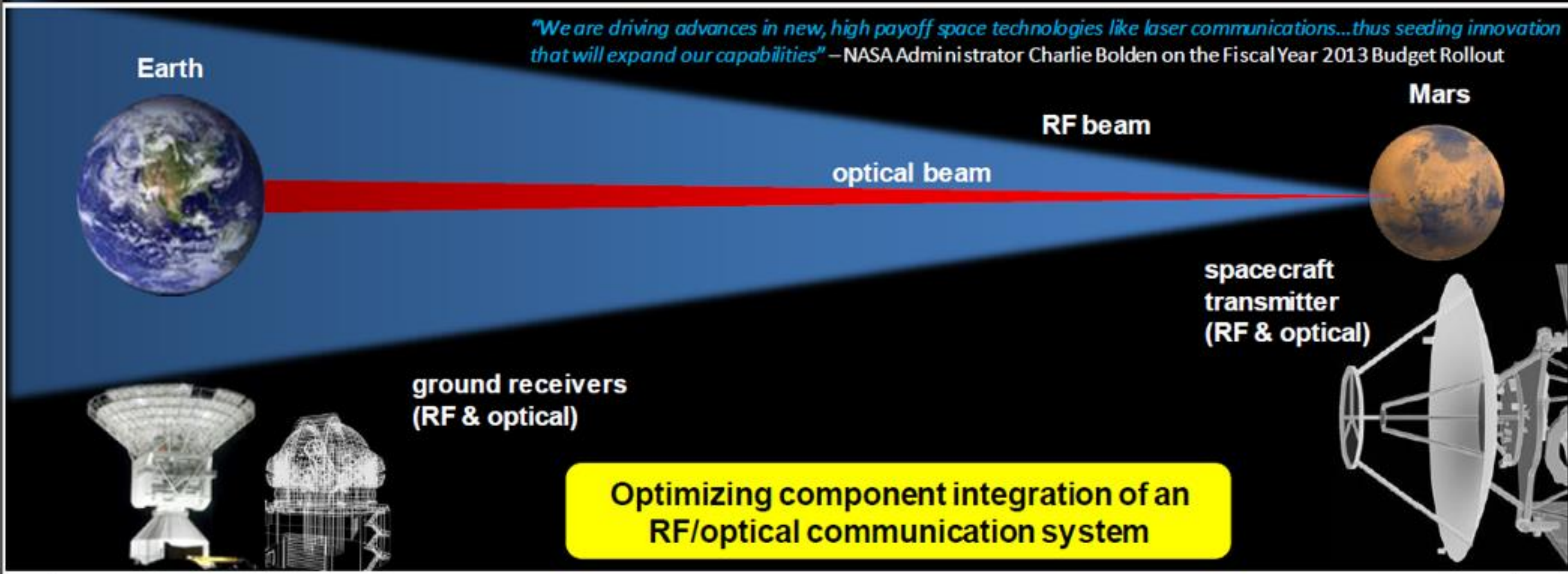
Deep Space Domain



SCaN Integrated Radio and Optical Communications (iROC)

The integrated RF/optical approach:

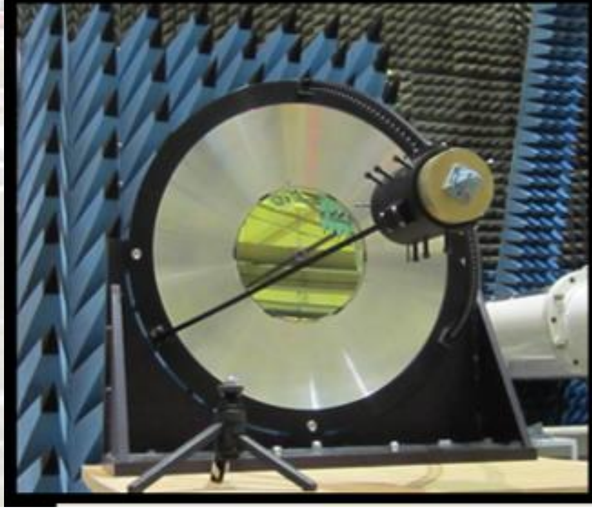
- Accelerates Gbps networked communication service through realizing a secure dual-band deep space trunk line, will not limit deep space science mission data return
- Offers an evolutionary approach to develop the operational readiness of optical communications technology for SCaN's integrated network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



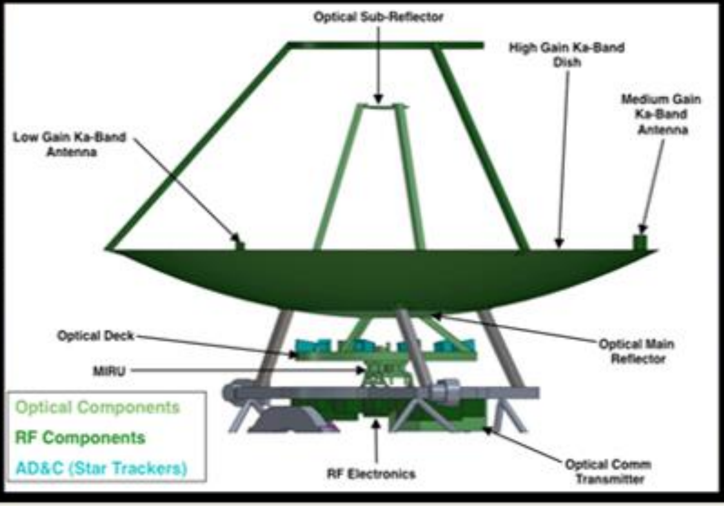
iROC Pointing, Acquisition and Tracking and the Hybrid RF/Optical Aperture are Highly Coupled

- 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

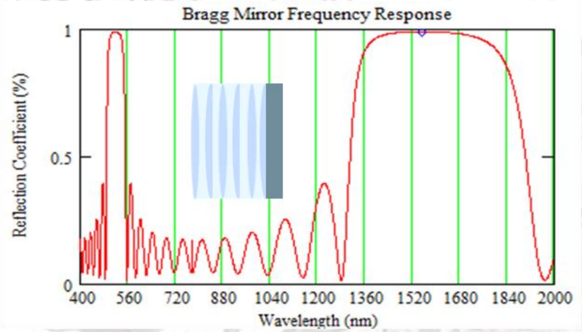


Telescope + Antenna = Teletenna

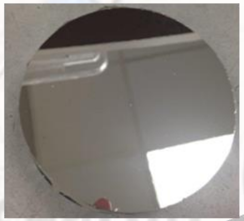


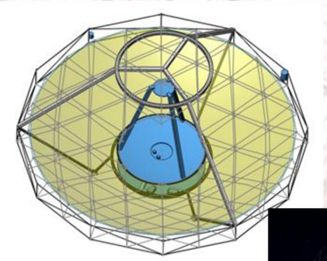
Beaconless Pointing Test- In Work

Integrated Radio Optical Communications— "Teletenna Concept"



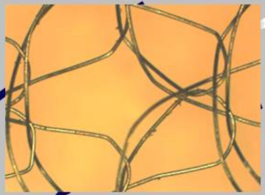
GRC developed microwave transparent Bragg optical sub-reflector


doubly curved graphite skin/aluminum core mirror coupons


Integrated Teletenna System

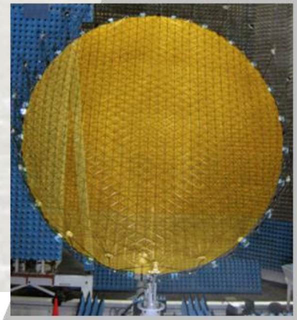

Large Deployable Mesh Antennas for Deep-Space Communications (NGST SMAP shown)

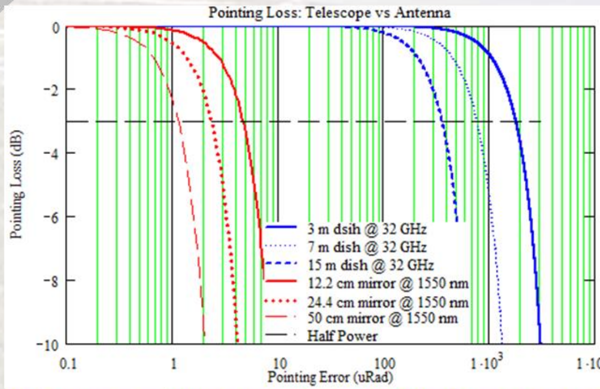
GRC/MicroEngineered Metals process developed to achieve <30 Å surface finish


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

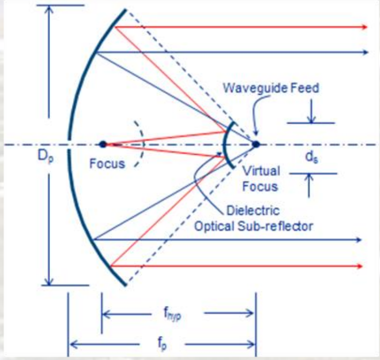
3 m Radio Antenna Material	25 cm Optical Mirror Material	Total Mass (kg)
Composite (16.7 kg)	Beryllium (0.5 kg)	17.2
Composite (16.7 kg)	Composite (0.1 kg)	16.8
Mesh (7.5 kg)	Composite (0.1 kg)	7.6

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

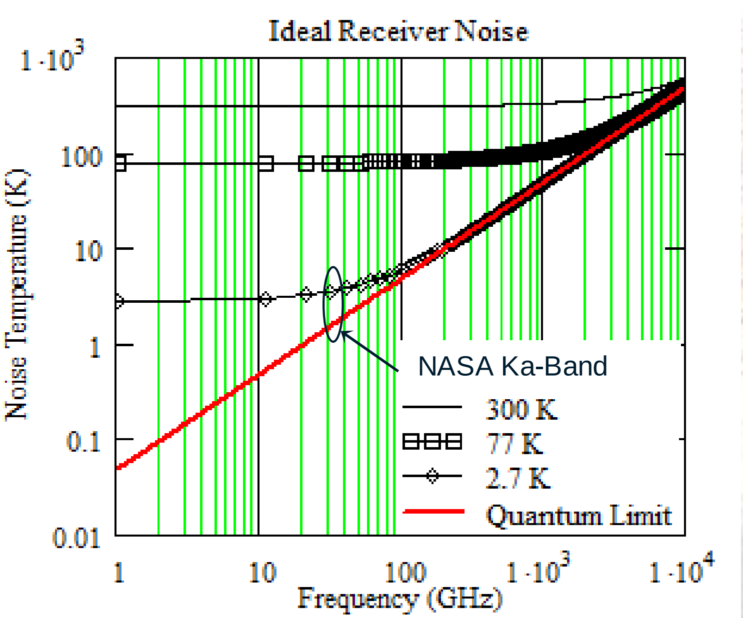


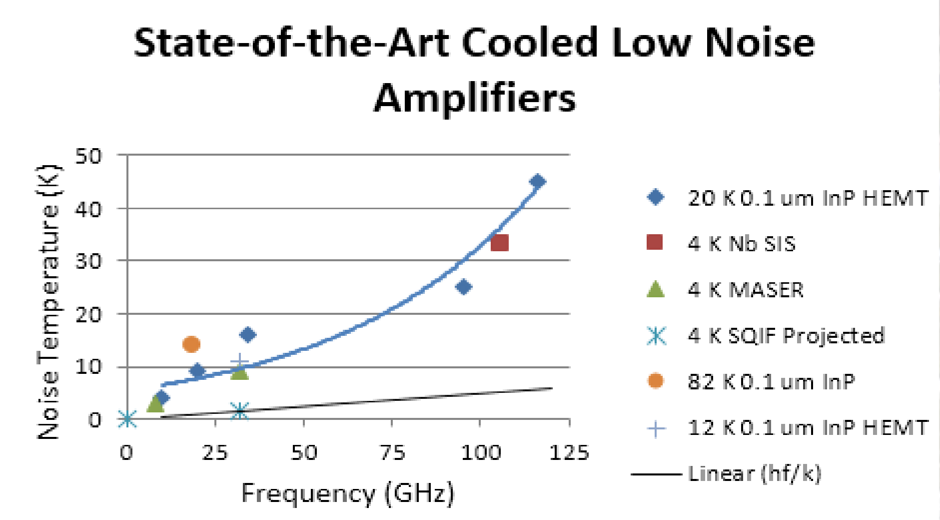
Hybrid Cassegrain/Prime Focus Telescope & antenna concept

Superconducting Quantum Interference Filter (SQIF)-Based Microwave Receivers

Superconducting Quantum Interference Filter-Based Microwave Receivers

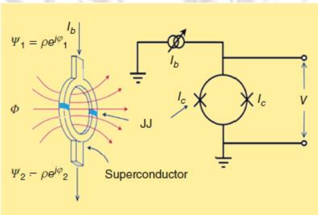
- Use <u>magnetic</u> instead of <u>electric</u> field detection to take advantage of highly sensitive Superconducting Quantum Interference Device (SQUID) arrays.
  - Proven and being used in medical and physics research, geology, etc.
- SQUIDs have a typical energy sensitivity per unit bandwidth of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



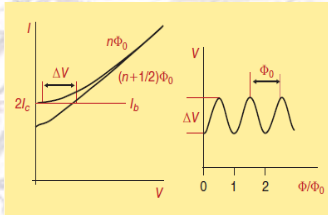


Superconducting Quantum Interference Filter (SQIF)

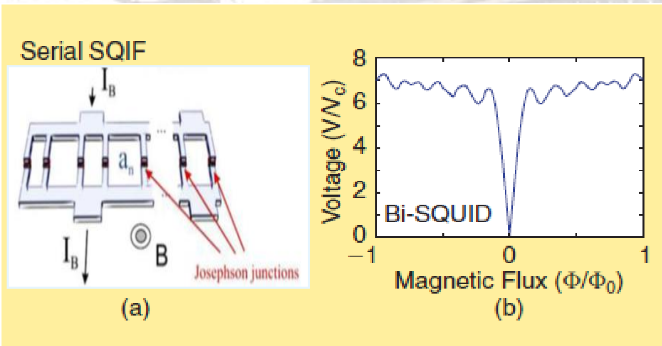
Operating Principles



A single SQUID

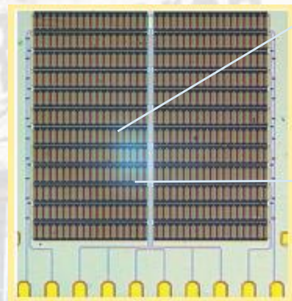


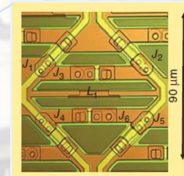
Periodic flux-to-voltage response



- 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 SQUID cells (S/N ~ $\sqrt{N}$)

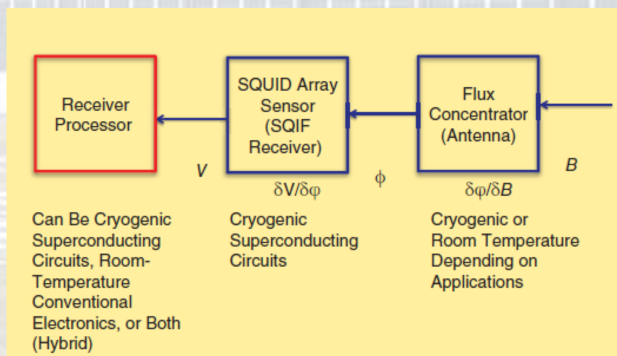
Integrated circuit of 2-D SQIF arrays





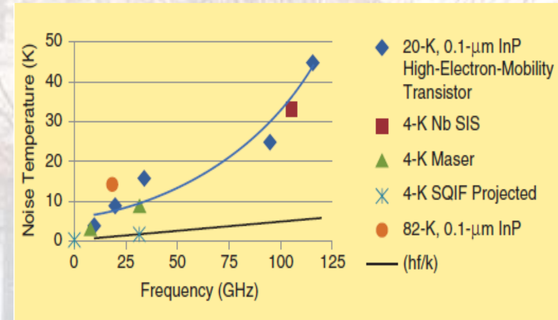
HYPRES Nb 2-D bi-SQIF array

SQIF receiver conceptual block diagram



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

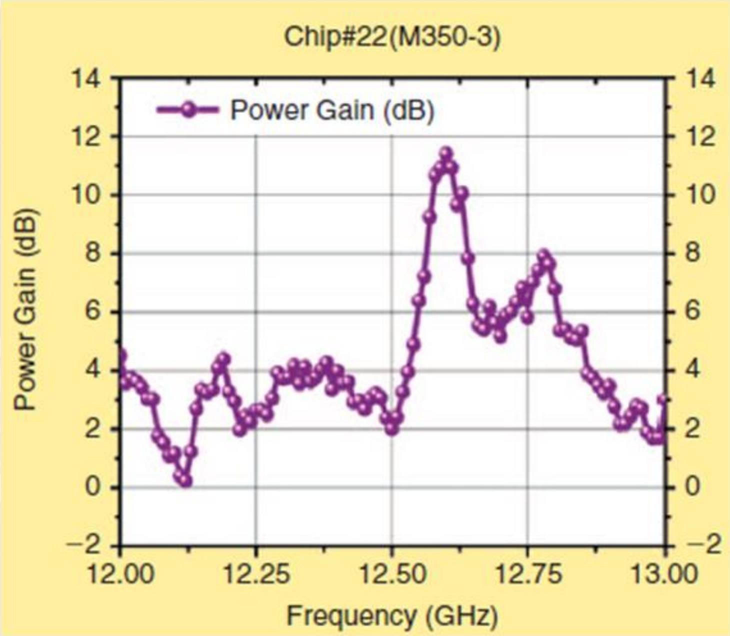
Comparative Technologies



- 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

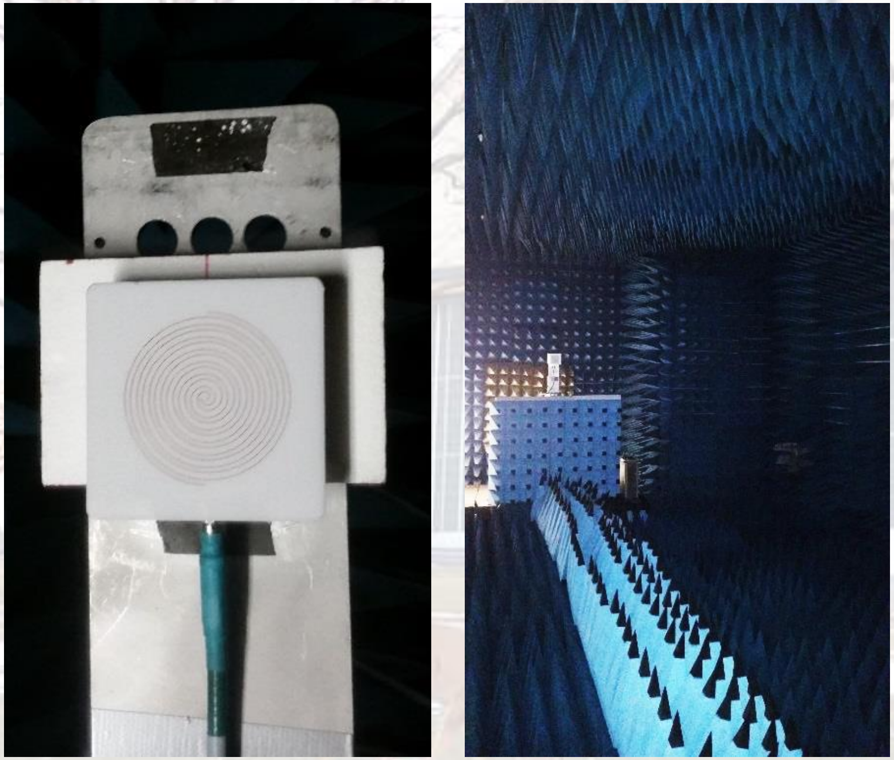
Focused Issue Featured Article: *Quantum Sensitivity: Superconducting Quantum Interference Filter-Based Microwave Receivers*



First reported X-band SQIF performance…

3D Printed Antennas for Cubesat / Smallsat Applications

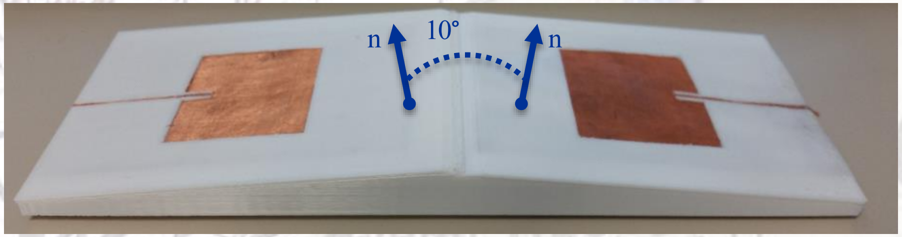
3D Printed Antennas – Archimedean Spiral

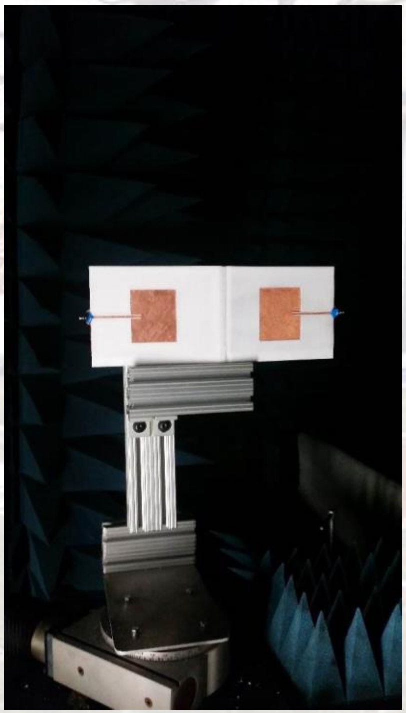


The embedded Archimedean spiral antenna under test in the NASA Glenn Research Center far-field antenna range.

- 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.

3D Printed Antennas – Multi-Planar Patch Antennas





The dual-plane microstrip patch antennas under test in the NASA GRC far-field antenna range.

Copper Foil

Copper Mesh

- Fabrication of structures on multiple non-parallel planes (10° offset)
- Multiple fabrication approaches to compare ease of fabrication/effects on performance:
  - Fine-pitch copper mesh
  - Fully dense copper foil
- Demonstrates capability for rapid prototyping of systems with multiple offset beams.

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.