NASA Activities as They Relate to Microwave Technology for Aerospace Communications Systems

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Abstract

This presentation discusses current NASA activities and plans as they relate to microwave technology for aerospace communications. The presentations discusses some examples of the aforementioned technology within the context of the existing and future communications architectures and technology development roadmaps. Examples of the evolution of key technology from idea to deployment are provided as well as the challenges that lay ahead regarding advancing microwave technology to ensure that future NASA missions are not constrained by lack of communication or navigation capabilities. The presentation closes with some examples of emerging ongoing opportunities for establishing collaborative efforts between NASA, Industry, and Academia to encourage the development, demonstration and insertion of communications technology in pertinent aerospace systems.

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NASA's Vision & Mission

NASA's Vision:

NASA leads scientific and technological advances in aeronautics and space for a Nation on the frontier of discovery

NASA's Mission:

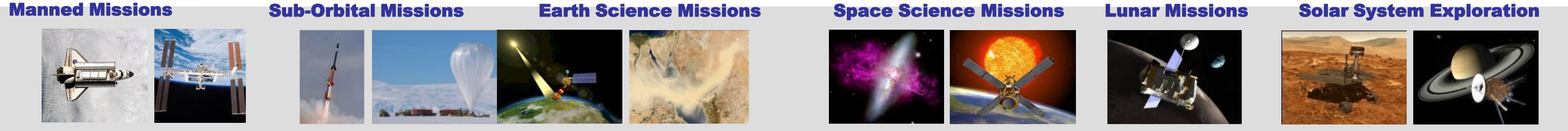
Drive advances in science, technology, and exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of the Earth.

Current NASA Space Communications and Navigation Network

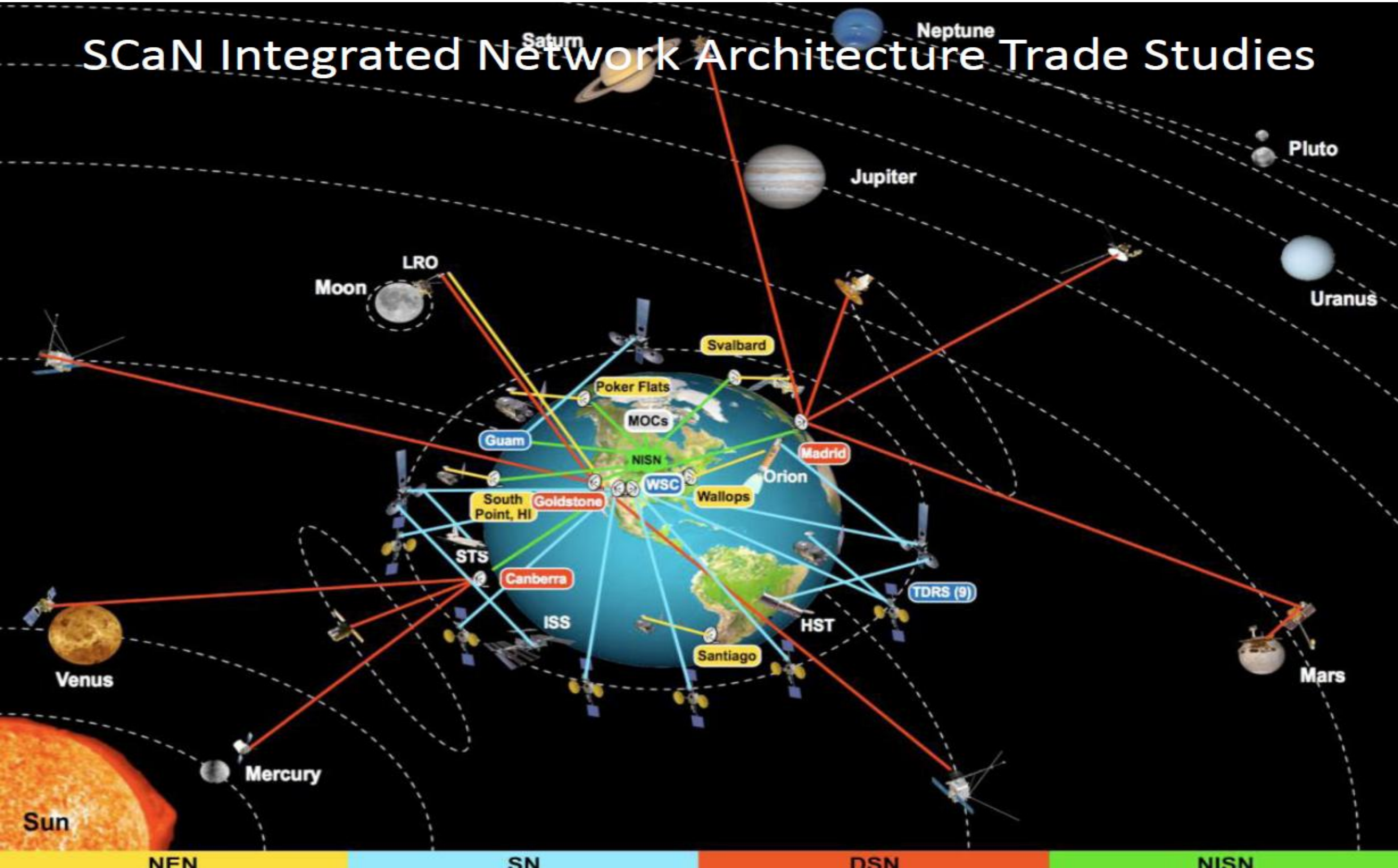
IEEE

MTT-S

WAMICON 2011



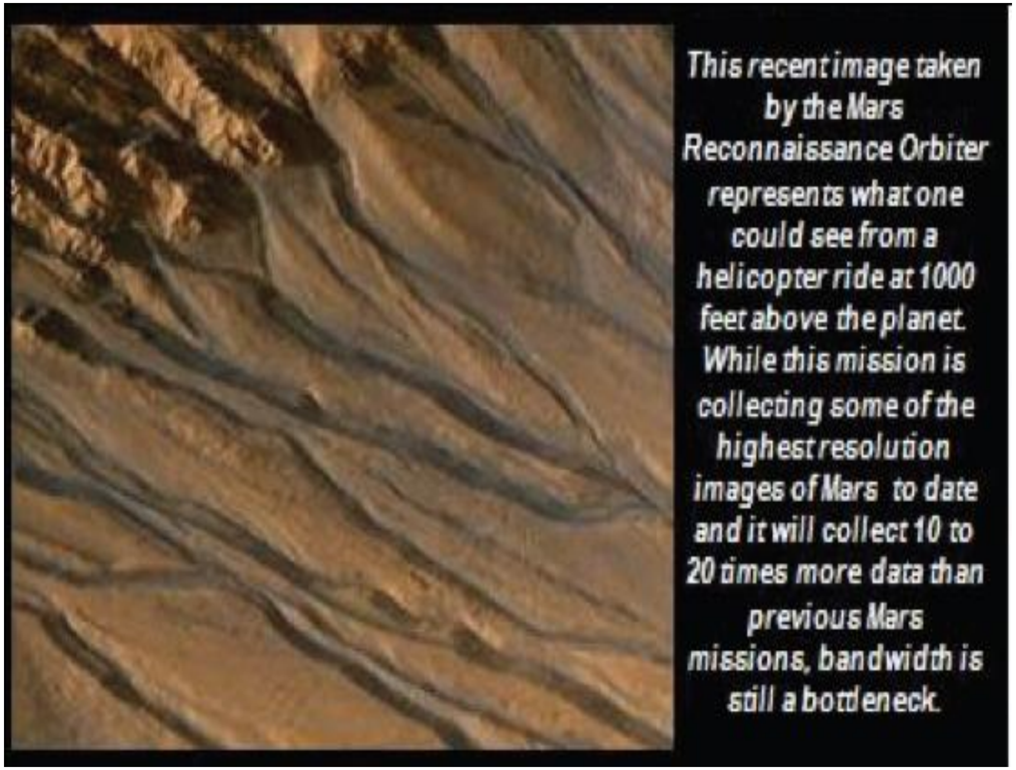
Future NASA Space Communications and Navigation Network



Communications – Lifeline to Missions[1]

- Deep Space Missions are constrained by limited data rates.

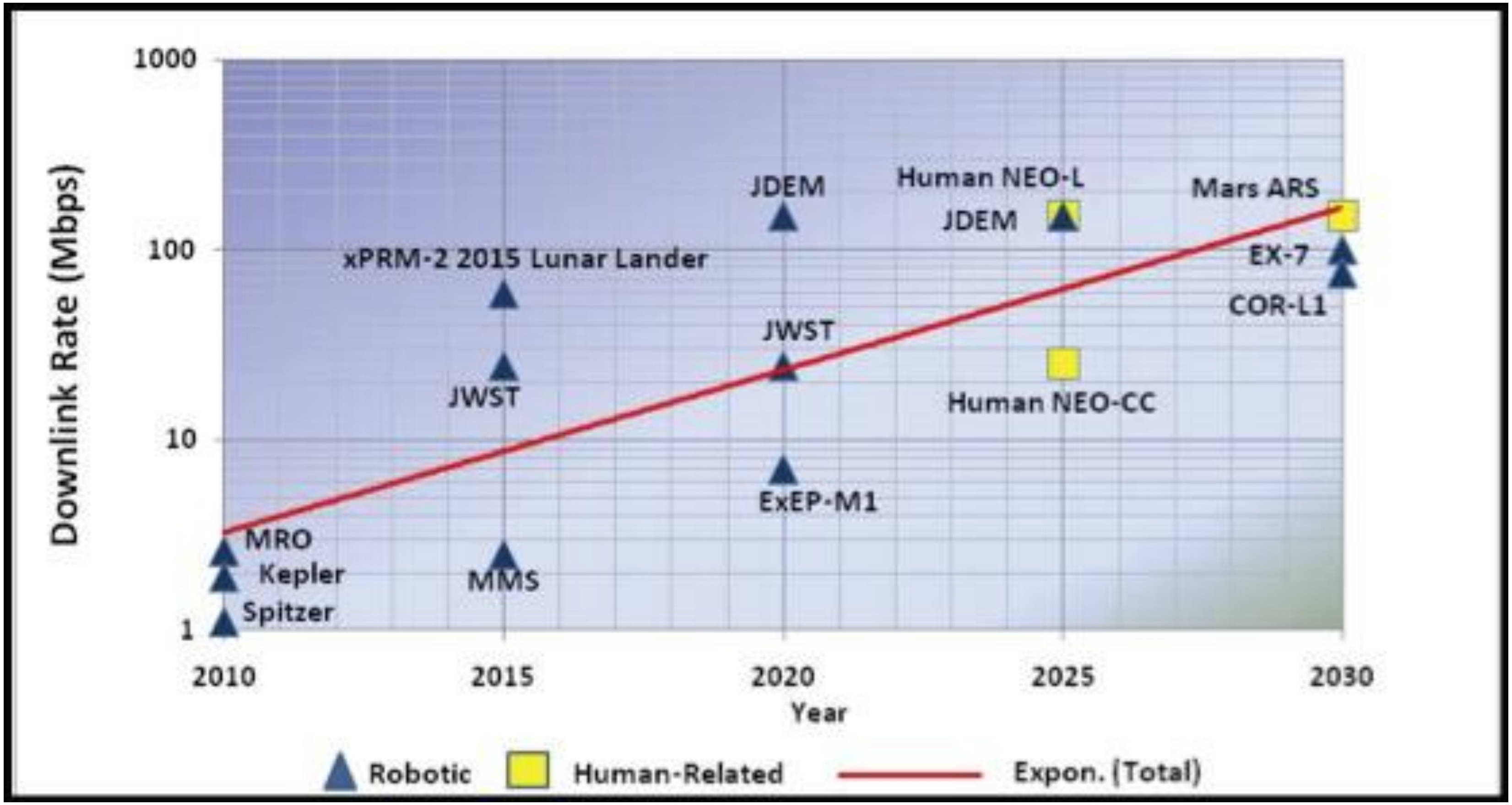
- For example, the full potential of MRO cannot be realized with the constraint of 6 Mbps data rate, with the following Implications:
  - 7.5 hrs to empty onboard recorder
  - 1.5 hrs to transfer a single High Resolution Image



Advanced Microwave or Optical Communication data links at 100Mbps will be able to empty the recorder in 26 min and transfer a High Resolution image every 5 mins!!

[1] **NASA OCT Communications and Navigation System Technology Area Strategic Roadmap**

Downlink Rate Drivers as a Function of Time

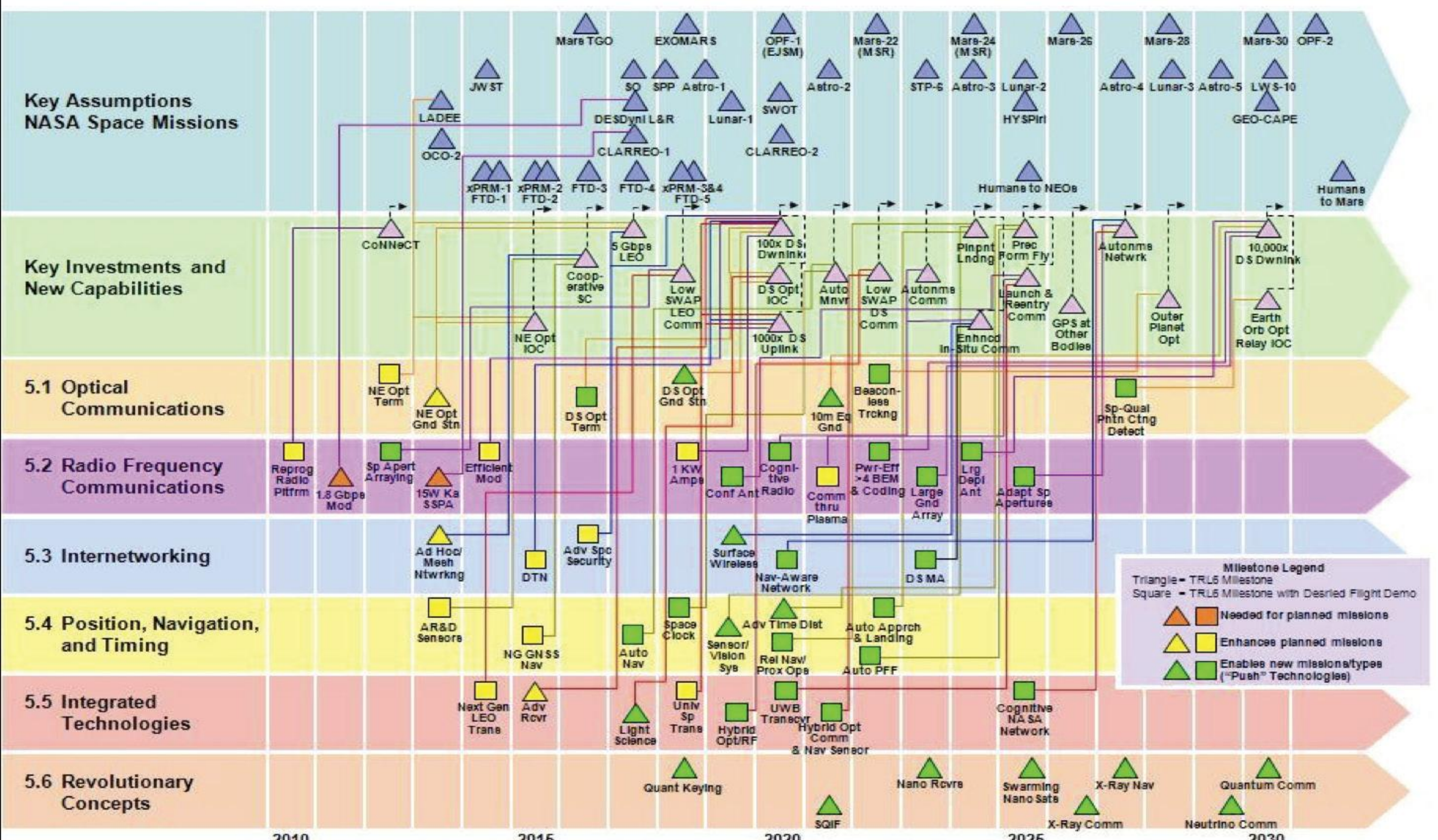


"Investments in communication and navigation technology will ensure that future NASA missions are not constrained by lack of communication or navigation capability"

--OCT Comm. & Nav. Systems Roadmap--

NASA OCT Communications and Navigation System Technology Area Strategic Roadmap

WAMICON 2011



(BEM - Bandwidth Efficient Modulation; DS - Deep Space; IOC - Initial Operational Capability; LEO - Low Earth Orbit; MA - Multiple Access; NE - Near Earth; SC - Spacecraft; Sp - Space; SWAP - Size, weight, and power; UWB - Ultra Wide Band)

OCT Technology Area Breakdown Structure

Sample: TA05, Comm. and Nav.

- **Communications and Navigation** (5)
  - **Optical Comm. and Navigation** (5.1)
    - Detector Development (5.1.1)
    - Large Apertures (5.1.2)
    - Lasers (5.1.3)
    - Acquisition and Tracking (5.1.4)
    - Atmospheric Mitigation (5.1.5)
  - **Radio Frequency Communications** (5.2)
    - Spectrum Efficient Technologies (5.2.1)
    - Power Efficient Technologies (5.2.2)
    - Propagation (5.2.3)
    - Flight and Ground Systems (5.2.4)
    - Earth Launch and Reentry Comm (5.2.5)
    - Antennas (5.2.6)
  - **Internetworking** (5.3)
    - Delay Tolerant Networking (5.3.1)
    - Adaptive Network Topology (5.3.2)
    - Information Assurance (5.3.3)
    - Integrated Network Management (5.3.4)
  - **Position, Navigation, and Timing** (5.4)
    - Timekeeping (5.4.1)
    - Time Distribution (5.4.2)
    - Onboard Auto Nav. & Maneuvering (5.4.3)
    - Sensors & Vision Processing Sys (5.4.4)
    - Relative and Proximity Nav (5.4.5)
    - Auto Precision Formation Flying (5.4.6)
    - Auto Approach and Landing (5.4.7)
  - **Integrated Technologies** (5.5)
    - Radio Systems (5.5.1)
    - Ultra Wideband (5.5.2)
    - Cognitive Networks (5.5.3)
    - Science From the Comm System (5.5.4)
    - Hybrid Opt Comm & Nav Sensors (5.5.5)
    - RF/Optical Hybrid Technology (5.5.6)
  - **Revolutionary Concepts** (5.6)
    - X-Ray Navigation (5.6.1)
    - X-Ray Communications (5.6.2)
    - Neutrino-Based Nav and Tracking (5.6.3)
    - Quantum Key Distribution (5.6.4)
    - Quantum Cmmunications (5.6.5)
    - SQIF Microwave Amplifier (5.6.6)
    - Reconfigurable Large Apertures (5.6.7)

OCT Communications and Navigation Technology Challenges

- Ensure that communications and navigation systems <u>do not become a constraint</u> in planning and executing NASA's mission.

- As NASA missions move farther from Earth communication and navigation technology must <u>minimize the impact of latency</u> in planning and executing NASA space missions.

- In advancing the capabilities of the communication and navigation systems to improve their performance we must assure that we <u>minimize user mass, power and volume burden</u> to the missions.

- The envisioned goal of servicing a wider and more interactive public must assure that we provide <u>integrity and assurance of information</u> delivery across the solar system.

- Communication and navigation services must me realized with <u>reduced lifecycle costs.</u>

- In order to validate and infuse new communication and navigation technology we must demonstrate to missions that it <u>performs with acceptable risk</u>.

Examples of Key Technology Development Activities at Glenn Research Center

- Traveling-Wave Tube Amplifiers for Space Communications
- Ferroelectric Reflectarray Antenna
- Large Aperture Deployable Antennas
- Software Defined Radios-Space Telecommunications Radio System (STRS)
- CoNNeCT
- Ka-Band Propagation Studies
- Antenna Arraying
- Delay/Disruption Tolerant Networking

High Power and Efficiency for Traveling-Wave Tube Amplifiers for Space Communications

2011

The Road From Idea to Deployment

LRO TWTA

Lunar Missions: 2007-2011

- *Delivered a 40 watt space TWTA to the Lunar Reconnaissance Orbiter*

Jupiter Mission – Higher FoM: 2004-2006

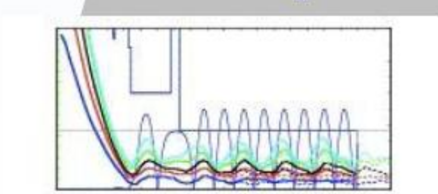
- *Space qualified a Ka-Band space TWT with output power of 200 watts, efficiency of 62 % and mass of 1.5 kg. Output power 20X higher than the Cassini TWT and the FoM was about 133*

Mars Mission – Higher Power & Efficiency: 2001-2003

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

Cassini Mission: 1996-2000

- *Delivered a Ka-Band space TWT with output power of 10 watts, efficiency of 41 % and mass of 0.750 kg for the Cassini mission. The figure of merit (FoM) which is power/mass was about 13*



Modeling & Simulations: 1980-1995

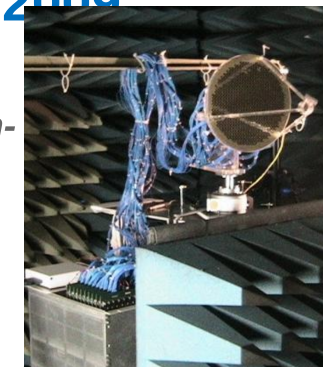
- *Basic design studies on traveling-wave tube (TWT) slow wave interaction circuits, collector circuit, focusing structure, electron gun and cathode*

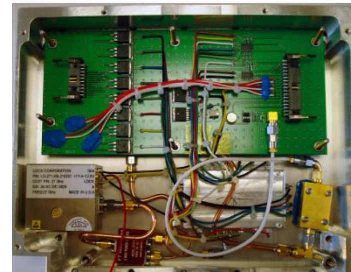
Ferroelectric Reflectarray Antenna
The Road From Idea to Deployment

2011

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

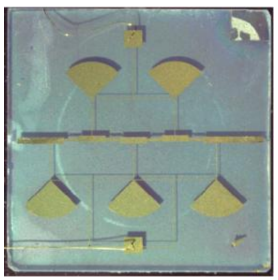




MISSE-8 Space Experiment: 2010

Cellular Reflectarray: 2010

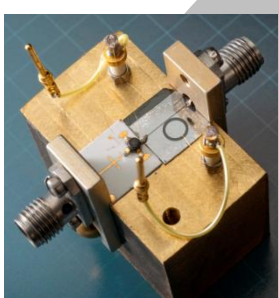
Derivative attracts attention for commercial next generation DirecTV, etc. applications



Thin film ferroelectric phase shifter on Magnesium Oxide

Practical Phase Shifters : 2003-2004

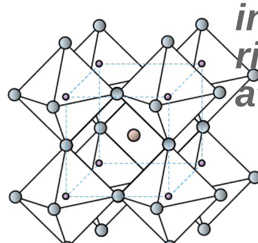
Novel phased array concept based on quasi-optical feed and low-loss ferroelectric phase shifters refined. 50 wafers of $Ba_{0.5}Sr_{0.5}TiO_3$ on lanthanum aluminate processed to yield over 1000 ferroelectric K-band phase shifters. Radiation tests show devices inherently rad hard in addition to other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



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

Large Aperture Deployable Antennas

The Road From Idea to Deployment

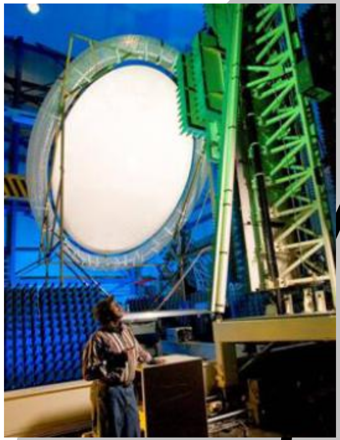
Prototype Inflatable Radome Antenna System at GRC

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.

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

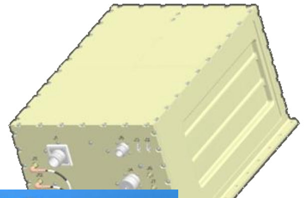
Designed and fabricated a 4x6m off-axis inflatable thin film antenna with a rigidized support torus. Characterized the antenna in the NASA GRC Near Field Range at X-band and Ka-band. Antenna exhibited excellent performance at X-band. Ka-band surface errors are understood.

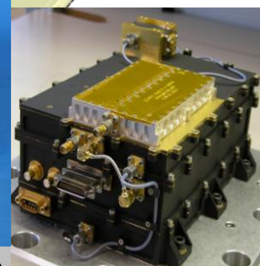
Seedling Idea: 2004

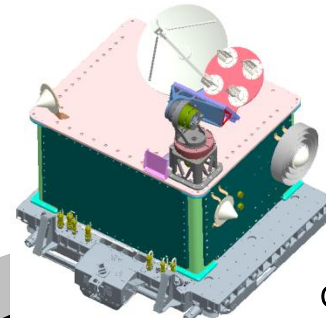
Circa 2004 need for large aperture deployable antenna identified for JIMO and Mars Areostationary relay platform. Antenna technology adapted from 1998 Phase II SBIR solar concentrator project.

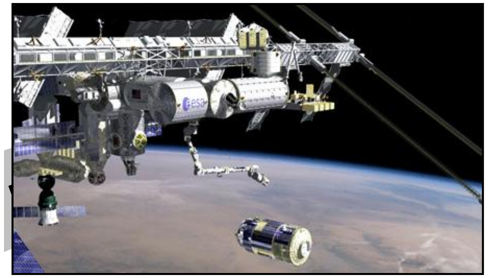
Software Defined Radios-Space Telecommunications Radio System (STRS) Architecture

2010 - CoNNeCT Flight Radios Developed by General Dynamics, Harris Corp., JPL









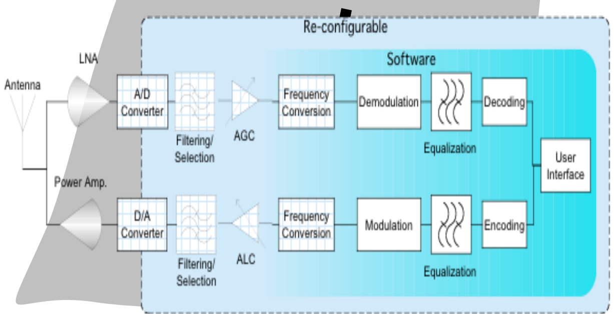
CoNNeCT Launch to ISS – Jan 2012

Flight Technology Demonstration: 2008 – 2011

Communications, Navigation and Networking re-Configurable Testbed (CoNNeCT) Project established to perform system prototype demonstration in relevant environment (TRL-7)

SDR Technology Development: 2005 – 2007

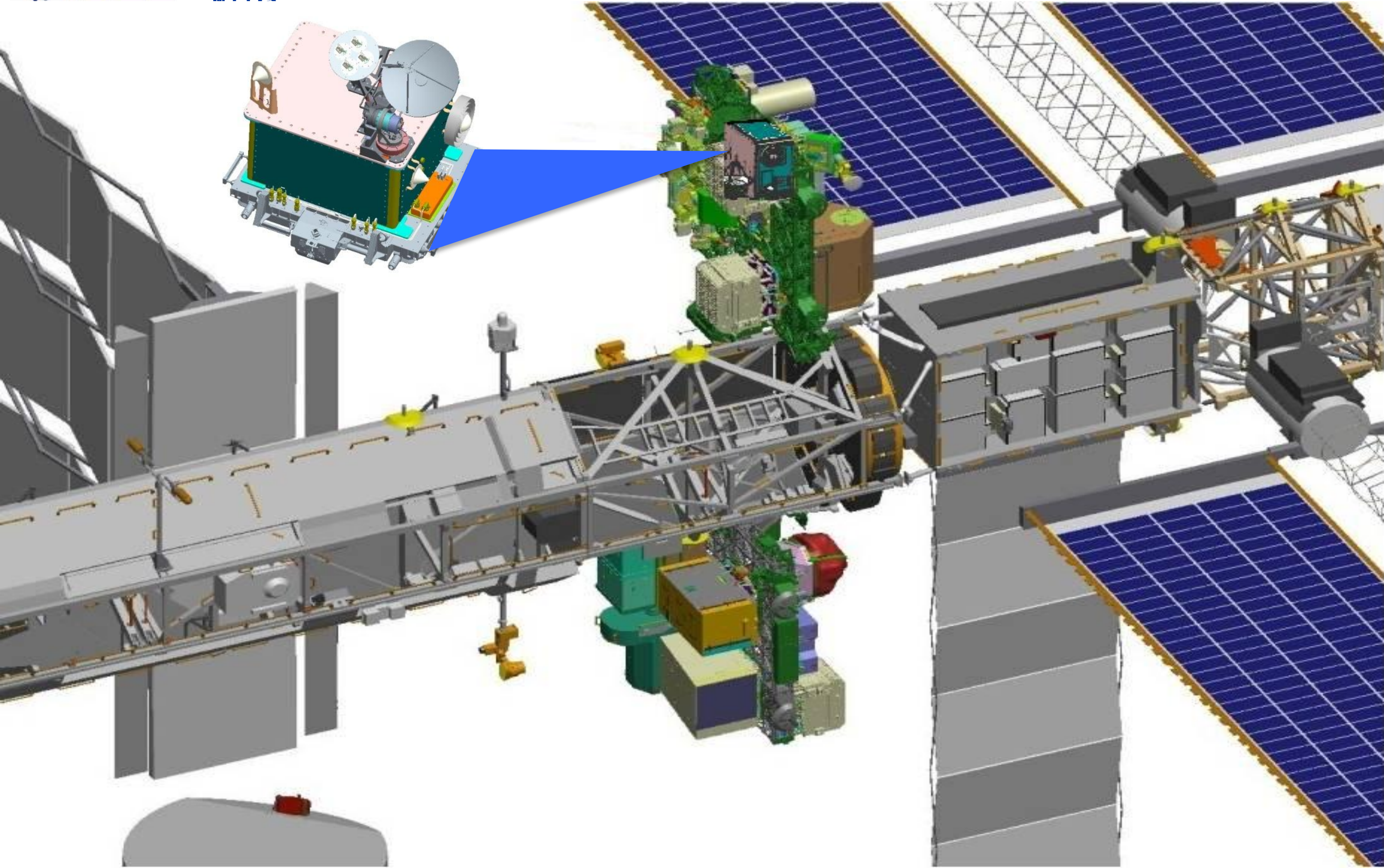
Development of design tools and validation test beds.
Development of design reference implementations & waveform components.
Establish SDR Technology Validation Laboratory at GRC.
NASA/Industry Workshops conducted



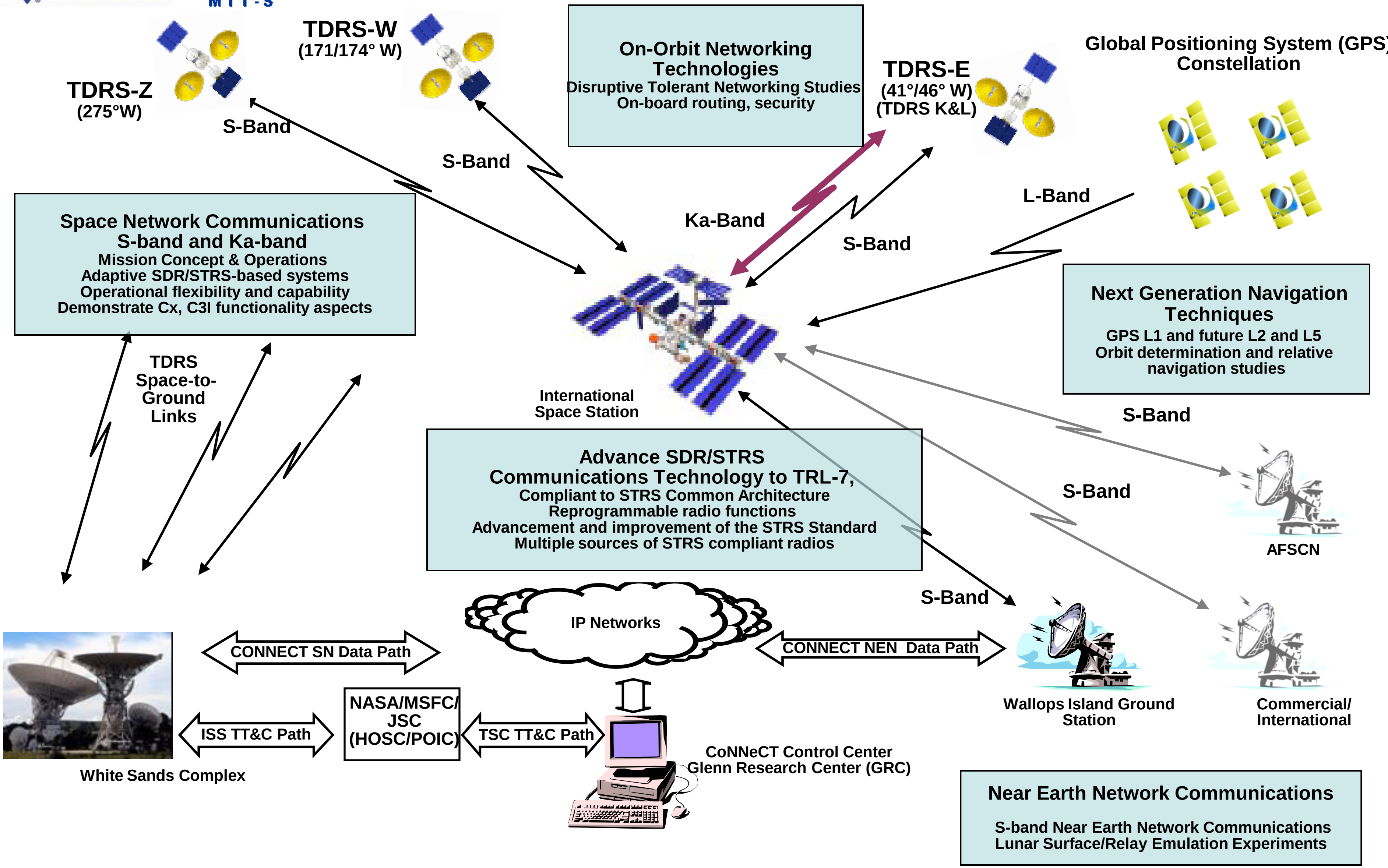
Open Architecture Development and Concept Formulation: 2002 – 2005

Develop common, open standard architecture for space-based software defined radio (SDR) known as Space Telecommunications Radio System (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.

CoNNeCT – Communications, Navigation and Networking reConfigurable Testbed



CoNNeCT Phase II Experiments Campaign

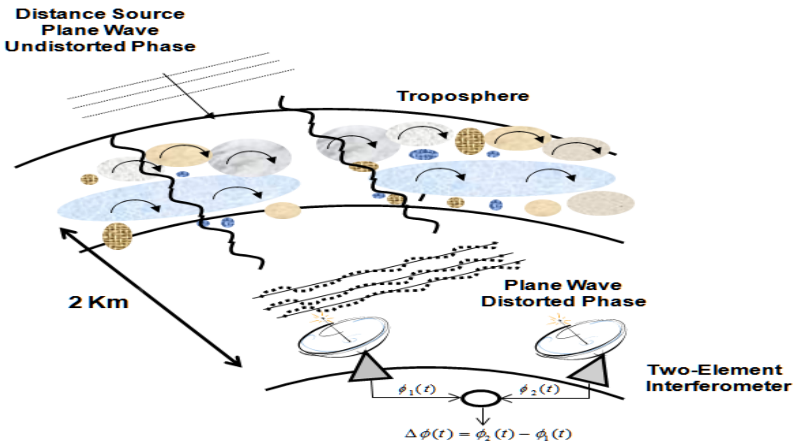


Ka-Band Propagation Studies

WAMICON 2011

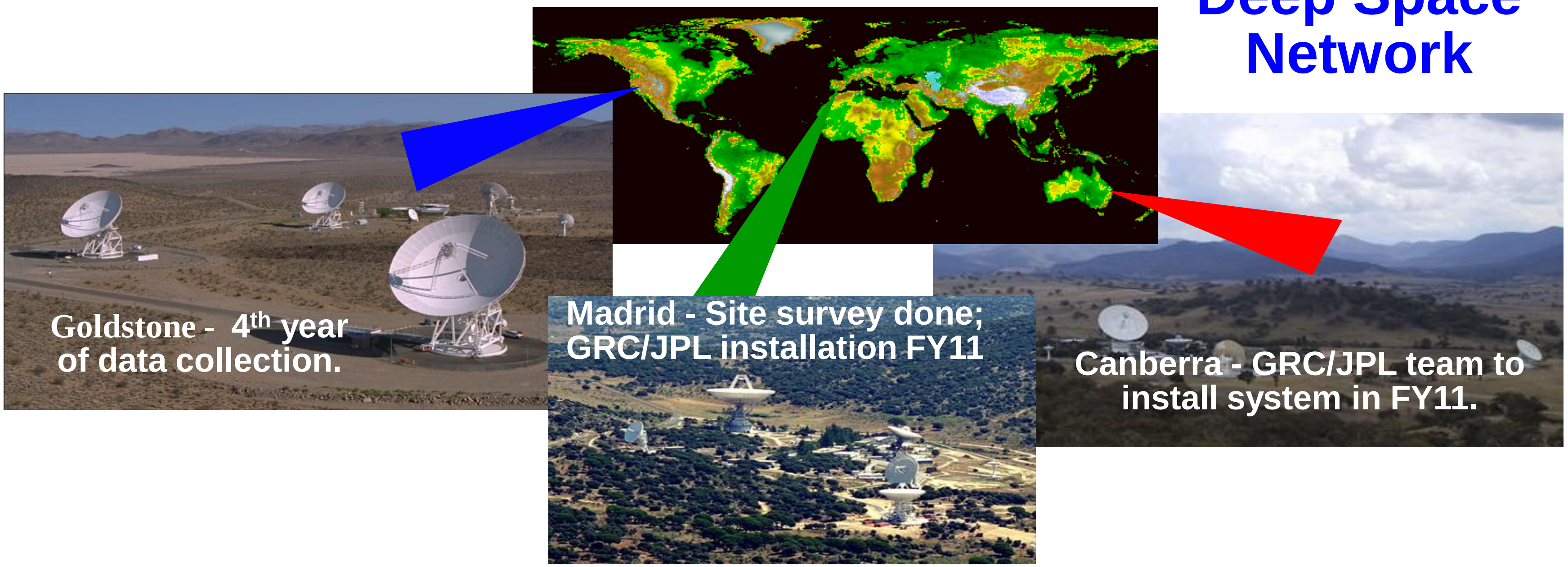
Objective: Understanding of atmospheric effects on distributed Ka-band systems at current and potential future NASA operational sites.

- Near Earth Network Sites (Guam, Svalbard, Norway)
- Space Network (White Sands, NM)
- Deep Space Network Sites

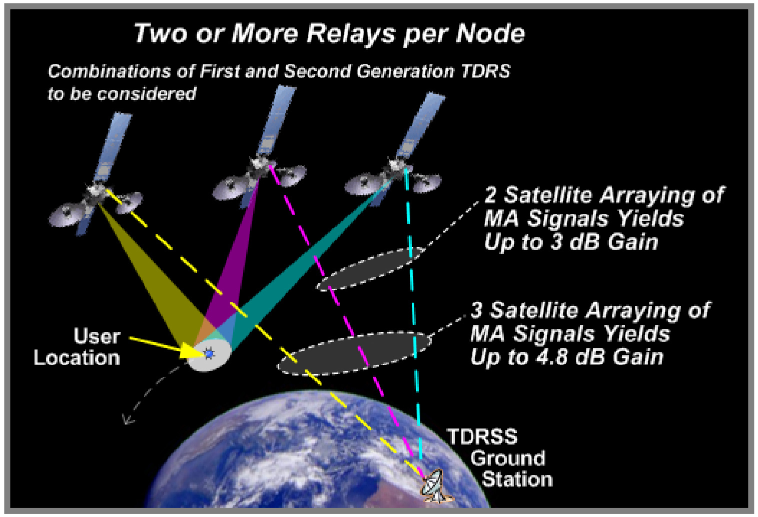


Technical Approach: *Statistical characterization* of the diurnal, annual and secular *path length fluctuations* at candidate sites for future distributed ground based antenna systems operating at Ka-Band.

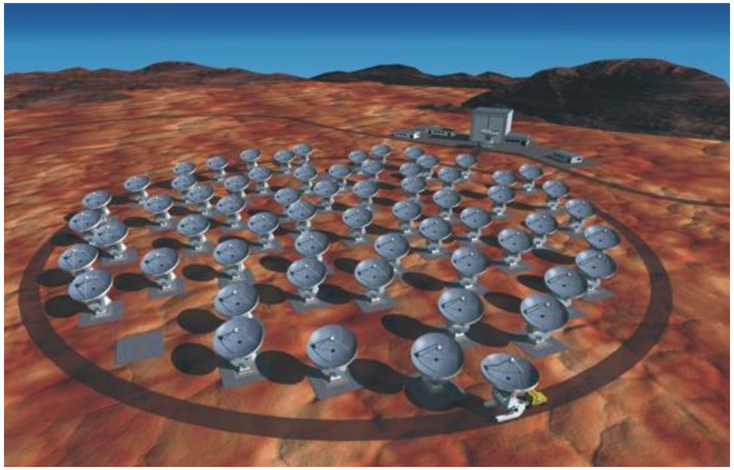
Deep Space Network



Antenna Arraying Technology



Satellite Arraying Concept

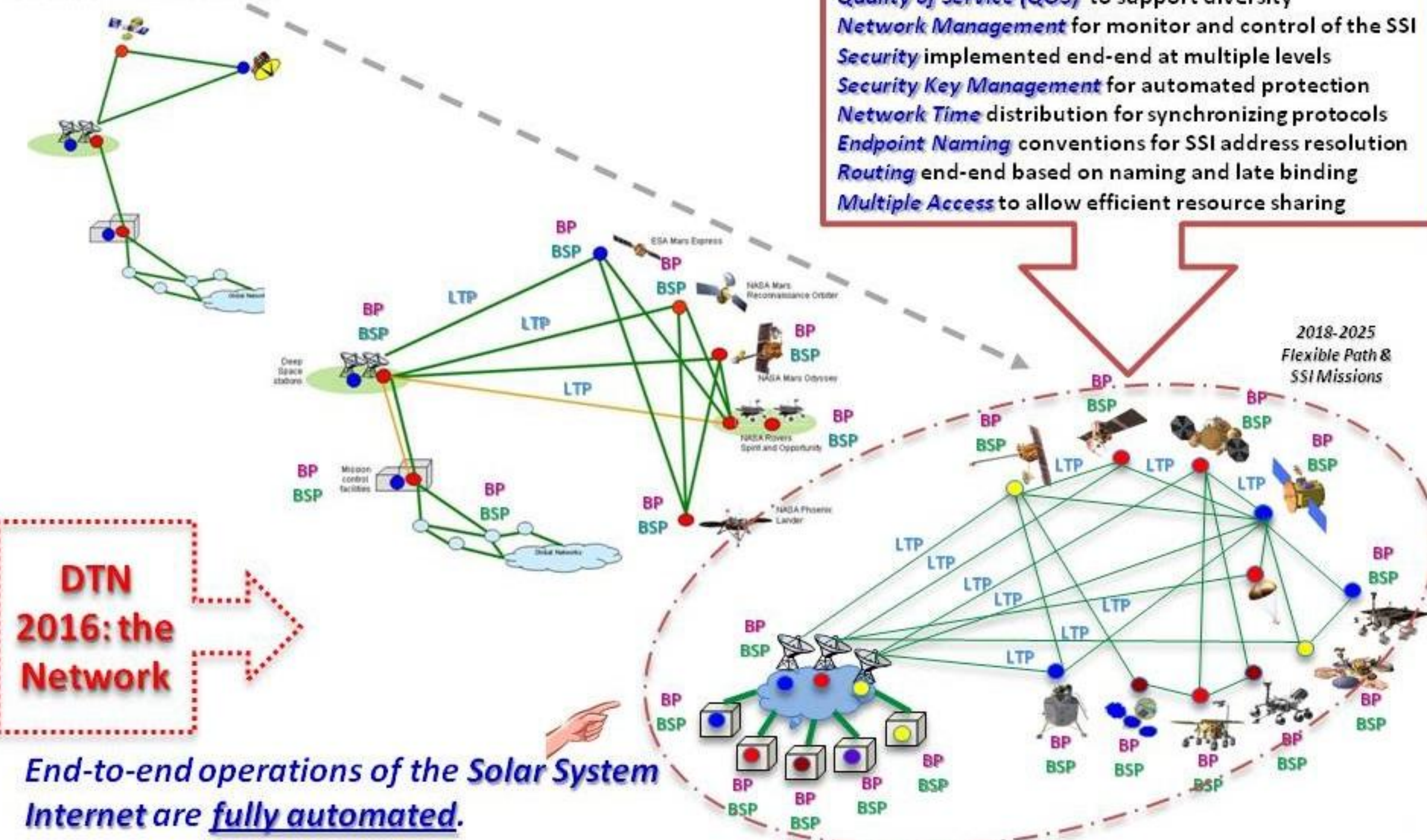


Ground Arraying Concept

Delay/Disruption Tolerant Networking (DTN)

Extension of Internetworking Protocols in Space

- ***DTN Applications*** to support SSI user operations
- ***Quality of Service (QOS)*** to support diversity
- ***Network Management*** for monitor and control of the SSI
- ***Security*** implemented end-end at multiple levels
- ***Security Key Management*** for automated protection
- ***Network Time*** distribution for synchronizing protocols
- ***Endpoint Naming*** conventions for SSI address resolution
- ***Routing*** end-end based on naming and late binding
- ***Multiple Access*** to allow efficient resource sharing



DTN 2016: the Network

End-to-end operations of the Solar System Internet are fully automated.

Summary

- Communications links are the lifelines to our spacecraft that provide the command, telemetry and science data transfers as well as navigation support

- Advancement in communication and navigation technology will allow future missions to implement new and more capable science instruments, greatly enhancing human and unmanned missions beyond Earth orbit, and enable entirely new mission concepts.

- There are emerging ongoing opportunities for establishing collaborative efforts between NASA, Industry, and Academia to encourage the development, demonstration and insertion of communications technology in pertinent aerospace systems:

    - OCT's: Early Stage Innovation: NASA Innovative Advanced Concept (NIAC) (NRA: NNH11ZUA001N)

    - OCT's Unique and Innovative Space "Game Changing" Technology (BAA: NNH11ZUA001K)

    - OCT's Technology Demonstration Missions (TDM) Program (BAA: NNM11ZDA001K)