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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The 12th Annual IEEE Wireless and Microwave Technology (WAMI) Conference
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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

Key Challenges
Integration/Transition of Networks (Technical, Cultural, Business)
Meeting Future High BW Needs
Reducing Overall Cost
Future NASA Space Communications and Navigation Network

SCaN Integrated Network Architecture Trade Studies
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
“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

Key Assumptions
NASA Space Missions

Key Investments and New Capabilities

5.1 Optical Communications

5.2 Radio Frequency Communications

5.3 Internetworking

5.4 Position, Navigation, and Timing

5.5 Integrated Technologies

5.6 Revolutionary Concepts

Milestone Legend
Triangle – TRL5 Milestone
Square – TRL6 Milestone with Desired Flight Demo

(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)
Ensure that communications and navigation systems do not become a constraint in planning and executing NASA’s mission.

As NASA missions move farther from Earth communication and navigation technology must minimize the impact of latency 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 minimize user mass, power and volume burden to the missions.

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

Communication and navigation services must me realized with reduced lifecycle costs.

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

The Road From Idea to Deployment

Lunar Missions: 2007-2011
- Delivered a 40 watt space TWTA to the Lunar Reconnaissance Orbiter

- 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

- 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

- 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

- 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

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.

Practical Phase Shifters: 2003-2004
Novel phased array concept based on quasi-optical feed and low-loss ferroelectric phase shifters refined. 50 wafers of $\text{Ba}_{0.5}\text{Sr}_{0.5}\text{TiO}_3$ 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 ($\text{Ba}_{0.5}\text{Sr}_{0.5}\text{TiO}_3$)], including oscillators, filters, antenna elements, etc., that rival or even outperform their semiconductor counterparts at frequencies up to Ka-band.

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

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

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

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

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

TDRS-W (171/174° W)
TDRS-Z (275° W)

Space Network Communications
S-band and Ka-band
Mission Concept & Operations
Adaptive SDR/STRS-based systems
Operational flexibility and capability
Demonstrate Cx, C3I functionality aspects

On-Orbit Networking Technologies
Disruptive Tolerant Networking Studies
On-board routing, security

TDRS-E (41°/46° W)
(TDRS K&L)

Global Positioning System (GPS) Constellation

Next Generation Navigation Techniques
GPS L1 and future L2 and L5
Orbit determination and relative navigation studies

Advance SDR/STRS Communications Technology to TRL-7,
Compliant to STRS Common Architecture
Reprogrammable radio functions
Advancement and improvement of the STRS Standard
Multiple sources of STRS compliant radios

IP Networks

CONNECT SN Data Path
CONNECT NEN Data Path

ISS TT&C Path
TSC TT&C Path

NASA/MSFC/JSC (HOSC/POIC)

CoNNeCT Control Center
Glenn Research Center (GRC)

Near Earth Network Communications
S-band Near Earth Network Communications
Lunar Surface/Relay Emulation Experiments

AFSCN

Wallops Island Ground Station
Commercial/International

White Sands Complex
Ka-Band Propagation Studies

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.

Goldstone - 4th year of data collection.

Madrid - Site survey done; GRC/JPL installation FY11

Canberra - GRC/JPL team to install system in FY11.
Antenna Arraying Technology

Two or More Relays per Node
Combinations of First and Second Generation TDRS to be considered

User Location

2 Satellite Arraying of MA Signals Yields Up to 3 dB Gain

3 Satellite Arraying of MA Signals Yields Up to 4.8 dB Gain

TDRSS Ground Station

Satellite Arraying Concept

Ground Arraying Concept
Delay/Disruption Tolerant Networking (DTN)
Extension of Internetworking Protocols in Space

Classical Point-to-Point

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.
Communications links are the lifelines to our spacecraft that provide the command, telemetry and science data 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)