A Commentary on Reconfigurable Communications Systems in Support of NASA Mission

Dr. Félix A. Miranda
Deputy Chief, Communications and Intelligent Systems Division
NASA Glenn Research Center, Cleveland, OH 44135

Felix.A.Miranda@nasa.gov
Tel: 216.433.6589

2018 Workshop on Origami Antennas and Electromagnetics
and
Kickoff Meeting for the Center for Physically Reconfigurable and Deployable Multifunctional Antennas

September 13-14, 2018
Florida International University

The NASA John H. Glenn Research Center at Lewis Field

What is a reconfigurable?

Definition of reconfigure –

- To rearrange the elements or settings of something…
- To change the shape of something …
- To reorder, realign, reshape..

What is a reconfigurable antenna?

A reconfigurable antenna is an antenna whose physical or electromagnetic distinctive/fundamental parameters (i.e., size, frequency, radiation pattern, and polarization) could be altered in a controlled manner manner. Such reconfiguration could be either in response to human commands/inputs, e.g., via Software Defined Radio (SDR), or autonomously as induced via a cognitive/intelligent agent. More on this later in the talk…

Why Reconfigurable Communications Systems?

Traditional Satellite Communications Assets:

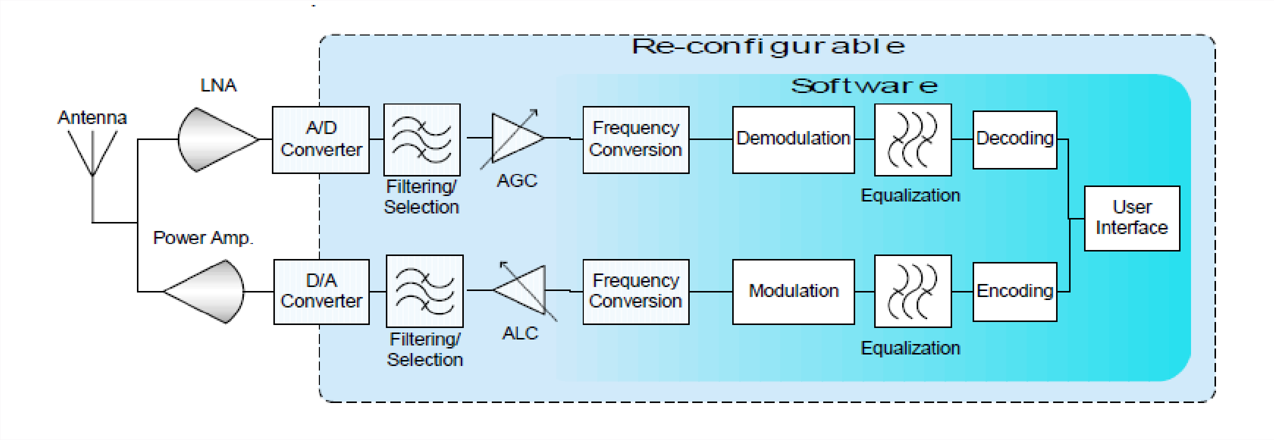
- Designed following very stringent specifications dictated by intended functionality, orbital placement, frequency of operation, power consumption, expected lifetime, etc.
- Lack flexibility…
- Upgrading in satellite series typically requires upgrade/advances in hardware with its concomitant high cost and development time implications, among others.

Reconfigurable Communication Systems:

- Can respond according to specific needs hence increasing versatility and usability of the asset.
- Potentially lower cost since reconfiguration is attained via waveforms inputs (e.g., software defined radio) as opposed to hardware changes
- NASA GRC is at the vanguard of reconfigurable communication systems via Software Define Radio (SDR) and Cognitive Systems for Space Communications.

Fundamentals of Software Defined Radios (SDRs)

- In today's communication systems, many functions including Coding and Modulation are implemented using Software Defined Radios (SDRs)
- With SDRs, functionality can be changed with updates to application software ("Waveforms") instead of hardware replacements. Fixed hardware is replaced with reprogrammable hardware such as Field Programmable Gate Arrays (FPGAs) and Processors
- SDRs enable increased capability with reduced Size, Weight, Power and Cost (SWaP-C)

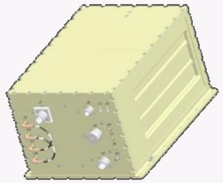


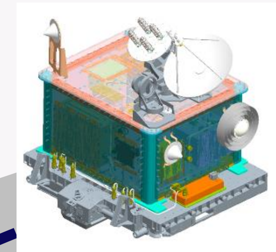
GRC has played a strong role in advancing the SOA in SDR technology

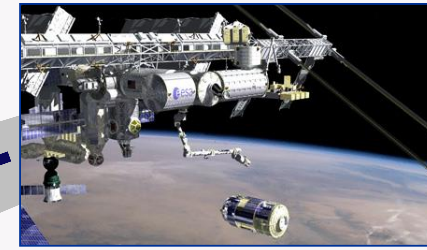
Ref: Richard C. Reinhart, Thomas J. Kacpura, Sandra K. Johnson, and James P. Lux, "NASA's Space Communications and Navigation Test Bed aboard the International Space Station," IEEE A&E Systems Magazine, April 2013.

Software Defined Radios-STRS Architectures

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



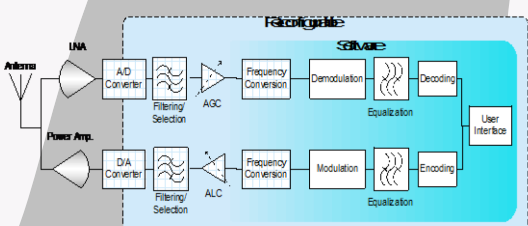




Technology Experiments: 2013 – 2018

Flight Technology Demonstration: 2008 – 2012
The Space Communications and Navigation (SCaN) Testbed (STB), established to perform system prototype demonstration in relevant environment (TRL-7). The STB was launched on July 12, 2012 to the ISS.

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



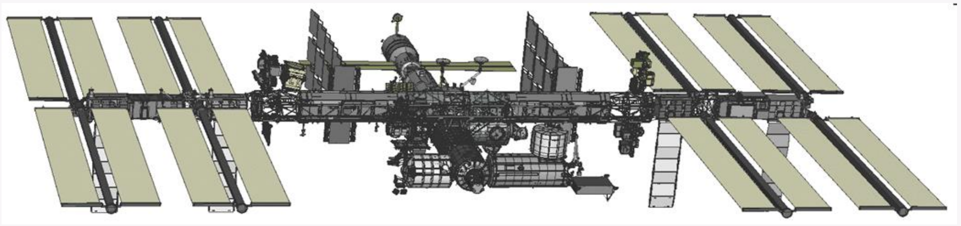
Open Architecture Development and Concept Formulation: 2002 – 2005
Develop common, open standard architecture for space-based software defined radio (SDR) known as Space Telecommunications Radio Architecture (STRS).
Allow reconfigurable communication and navigation functions implemented in software to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

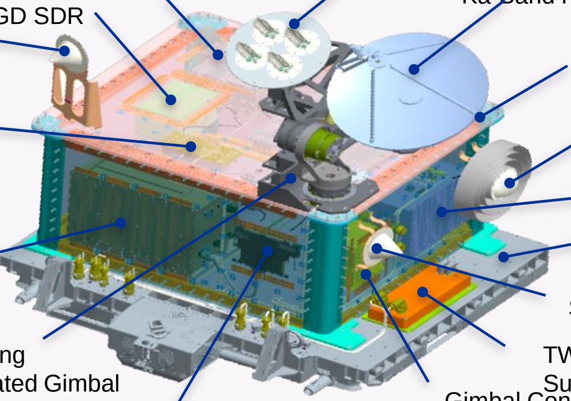
Advancing the SOA in Software Defined Radios

GRC developed the **Scan Testbed (STB)** - launched to the ISS 2012

- Technology Demonstration Mission to mature Communication, Navigation, & Networking technologies for application in space
- Highly modular software enabling in-orbit reconfiguration and multi-waveform operation
- Coding and modulation can be varied based on link conditions resulting in improved performance and efficiency.
- To date over 20 Consultative Committee for Space Data Systems (CCSDS) Protocols including IP over CCSDS, Delay Tolerant Networking & Digital Video Broadcasting - Satellite - Second Generation (DVB-S2) have been implemented.

Since 2002, GRC has led development of the Space Telecommunications Radio System (STRS) architecture standard for SDRs. Standard allows waveforms to be reused for different applications and on platforms developed by different vendors.



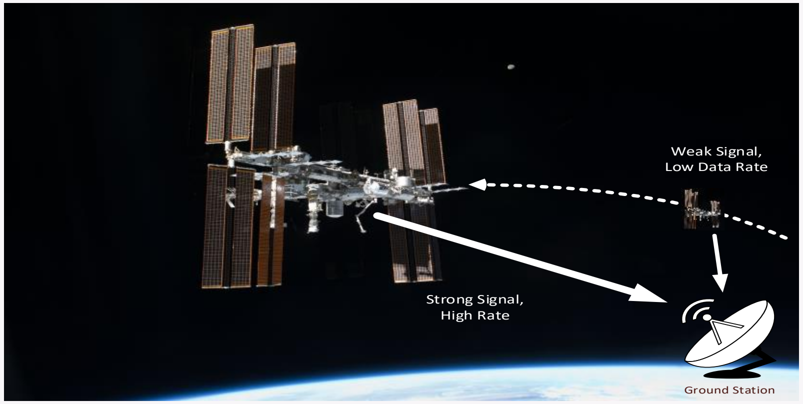


Roadmap to Cognitive Communications

Goal: Leverage STB and develop next generation cognitive technologies for communications to increase mission science return and improve resource efficiencies.

SCaN Test Bed is an early proving ground for experiments in cognitive communications

- Performed experiments in VCM and ACM
- Moving toward cognitive communications
  - More efficient use of spectrum, power and network resource management

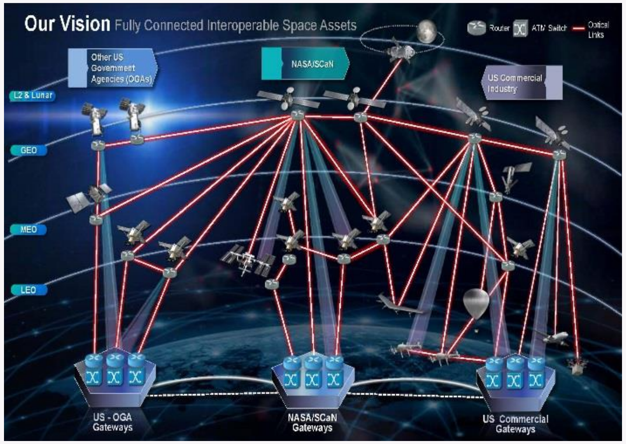


Automatically compensate for dynamic link environment

SDR → Variable Coding & Modulation (VCM) → Adaptive Coding & Modulation (ACM) → Cognitive Radio/System

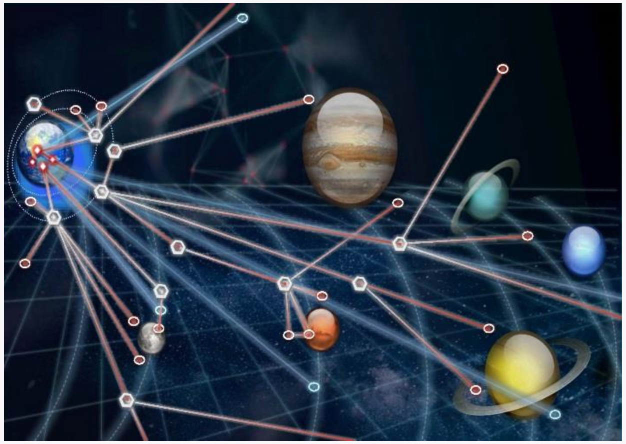
SDR	Variable Coding & Modulation (VCM)	Adaptive Coding & Modulation (ACM)	Cognitive Radio/System
Configurable Properties	Reconfigure system based on predictions	Dynamic reconfiguration based on feedback	Adapting and learning to form intelligent systems: cognitive radios, intelligent networking, user initiated services

Space Communications and Navigation Decade of Light Vision

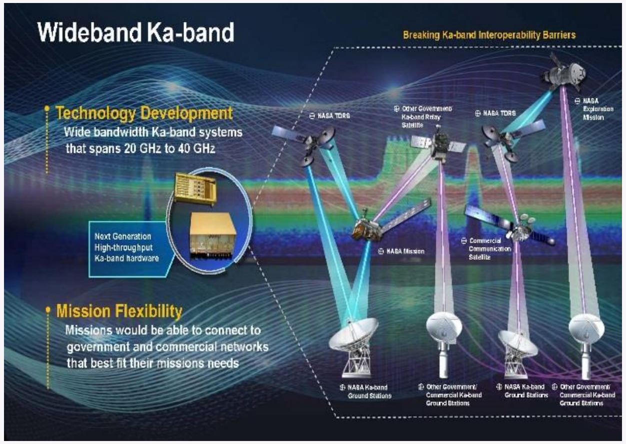


SCaN Next Generation Architecture

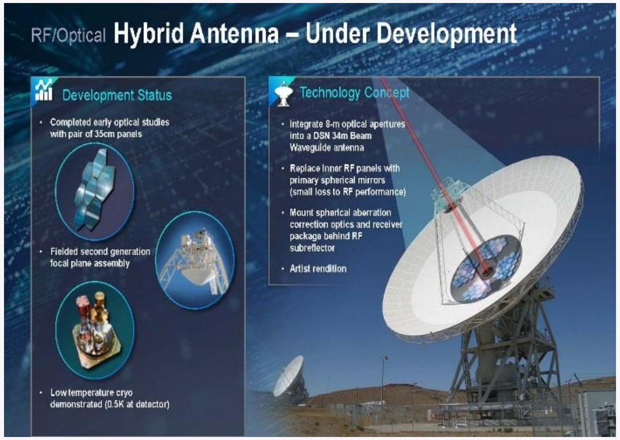
Optical & Ka-Band
Disaggregated
Software Defined
Multi Node
Networked
Delay/Disruption Tolerant
Autonomous
Interoperable
Affordable
Extensible

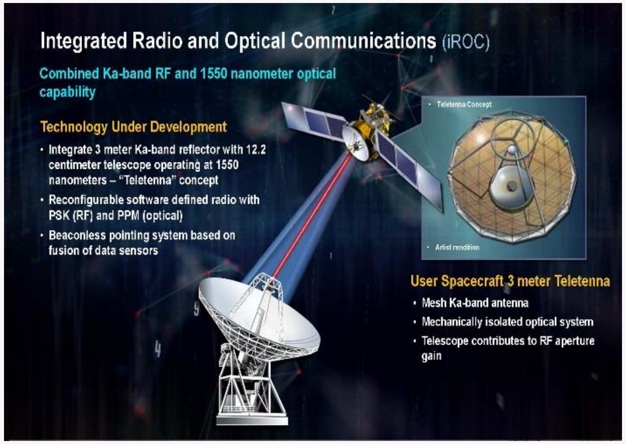


SCaN Interplanetary Network



Breaking Ka Band Interoperability Barriers





Hybrid Radiofrequency Optical Technology – Under Development

Ref: Mr. Badri Younes, Deputy Associate Administrator for Space Communications and Navigation (SCaN).

COGNITIVE LINKS

Adaptive coding and modulation with cognitive engines

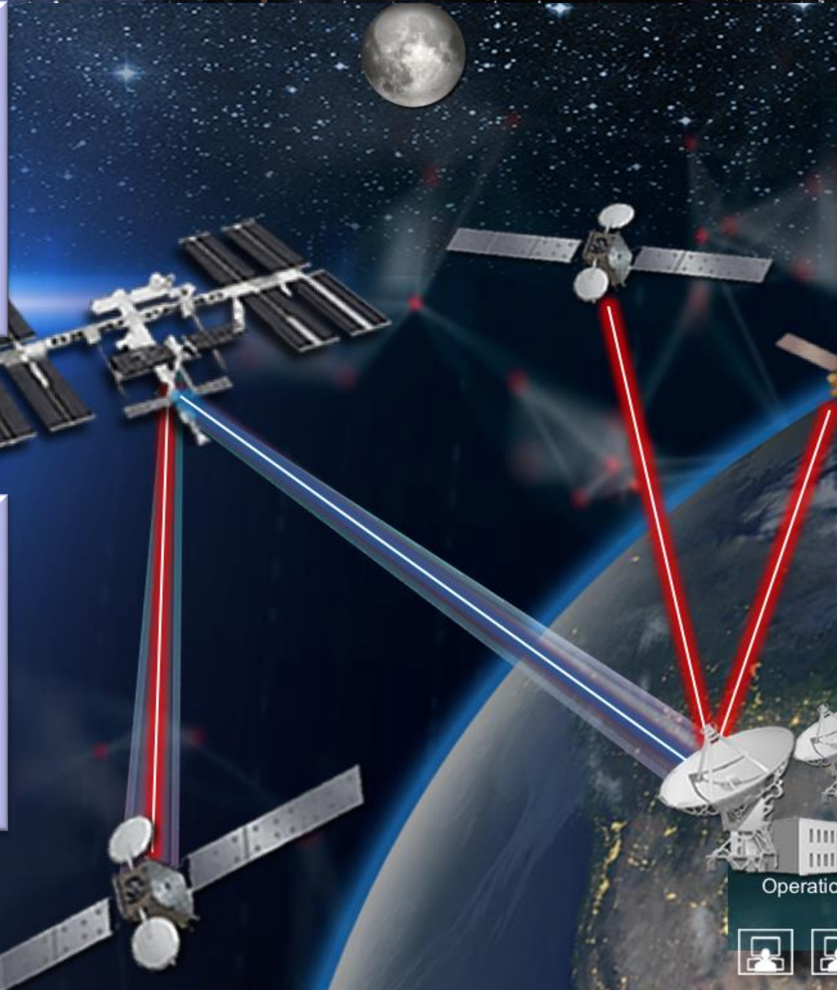
- *Choose optimal settings by predicting channel conditions*
- *Eliminate the need for calculating precise link budgets*

Radio Frequency (RF) interference mitigation

- *Automatically sense and avoid spectrum interference by changing frequency, bandwidth, and data rate*
- *Cognitive engines to identify and remove interference*

Self-configuration of radio by modulation recognition of signal

- *Perform signal recognition that allows self-configuration and link acquisition even with noise or weak signal*



Ref. Dr. Janette Briones (janette.c.briones@nasa.gov) SCaN Cognitive Communications

Cognitive compensation for propagation and nonlinear channel effects

- *Classify overall channel degradation by its component effects and mitigate each one appropriately*
- *Learned communication channel optimization (DeepSig)*

Optimal hand-off between Free Space Optical and RF links

- *Integrate FSO and RF seamlessly to form a unified transport*

COGNITIVE NETWORKS

Cross-layer optimization and discovery of network devices

- *Autonomously assign Quality of Service metrics to user data*
- *Discover capabilities of user radios on SCaN network*

Delay and disruption tolerance (DTN) over multiple hops

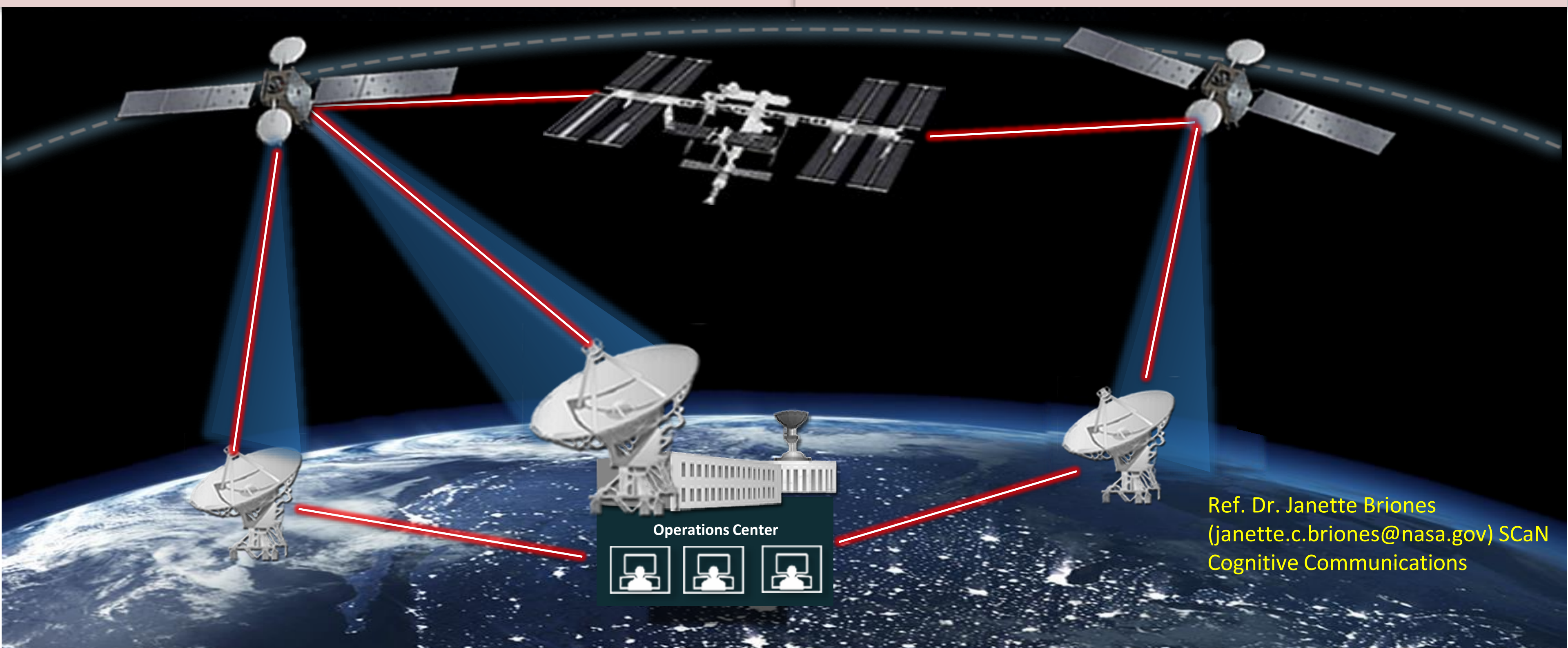
- *Apply CE to determine the optimal route through a space network with infrequent or distant nodes*

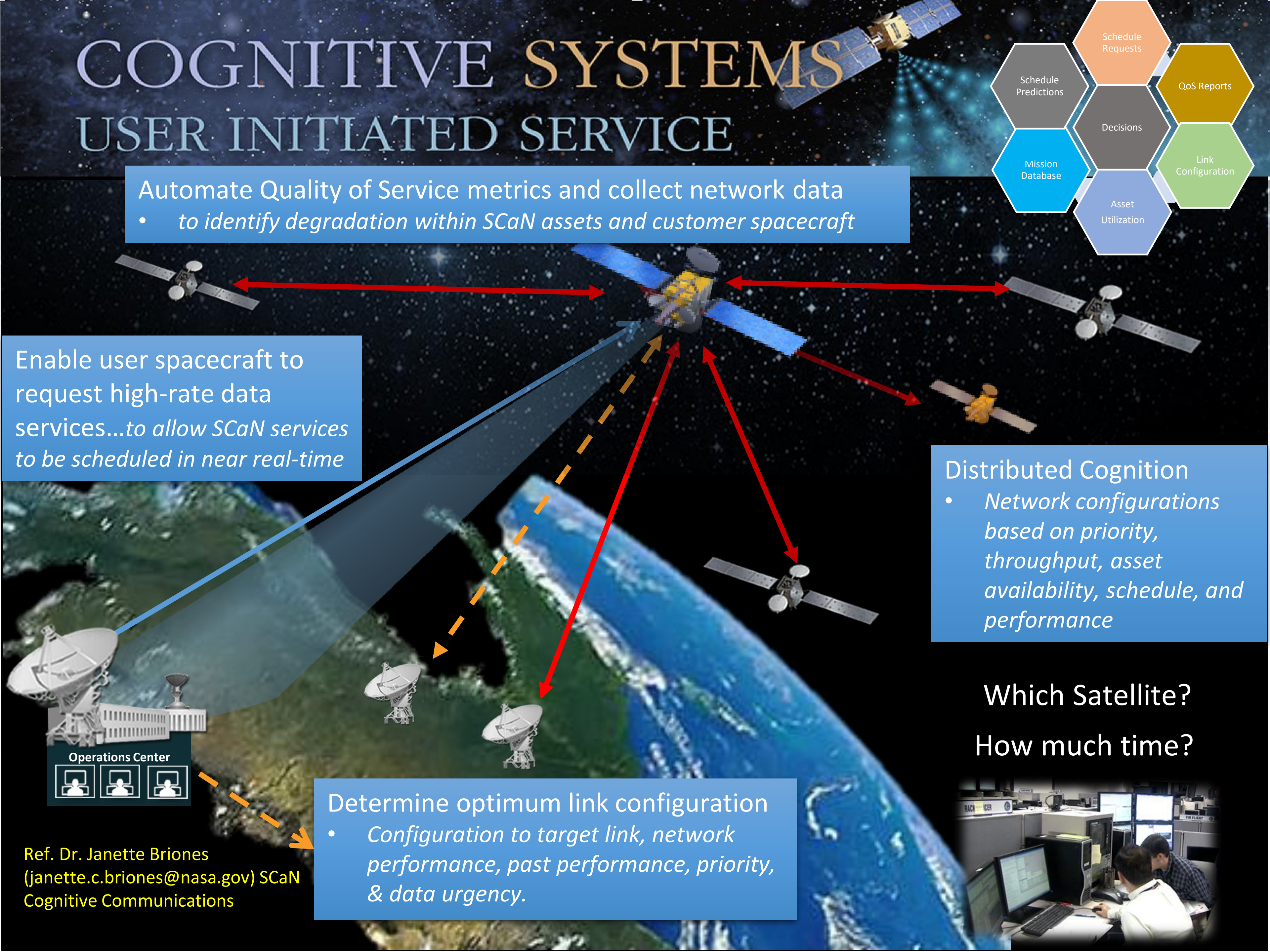
Drop user spacecraft data at any space or ground asset

- *Improve network management and responsiveness*
- *Eliminate the need for reserving specific assets for customers*

Network security for integration of commercial providers

- *To protect user data and provide flexibility when using third-party transport services*




COGNITIVE SYSTEMS
USER INITIATED SERVICE
Schedule Requests
Schedule Predictions
QoS Reports
Decisions
Mission Database
Link Configuration
Asset Utilization
Automate Quality of Service metrics and collect network data
• to identify degradation within SCaN assets and customer spacecraft
Enable user spacecraft to request high-rate data services…to allow SCaN services to be scheduled in near real-time
Distributed Cognition
• Network configurations based on priority, throughput, asset availability, schedule, and performance
Which Satellite?
How much time?
Operations Center
Determine optimum link configuration
• Configuration to target link, network performance, past performance, priority, & data urgency.
Ref. Dr. Janette Briones (janette.c.briones@nasa.gov) SCaN Cognitive Communications

To fully exploit the advantages of Cognitive Communications Systems the hardware should not be the communications bottleneck…

…Hence the reconfigurable antennas!!

Challenges of Antenna Reconfiguration

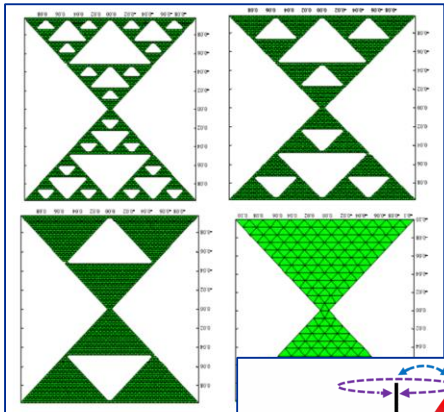
- Multiple functions within one radiating aperture; this can be achieved via,
  - Frequency Selective Surface – fulfill operations at a variety of frequencies
  - Ultra-Wide Band Antennas – communication and sensing; radar/radiometry[1,2]
  - Phased Array Feed Antennas (PAFA)– Multiple Beams, Multiple frequency antennas
- All along while maintaining quality of operation upon multiple reconfigurations, scanning, etc.
  - Impedance Matching
  - Gain/Directivity
  - Efficiency
  - Others
- Burden/requirements on Materials/components
  - Resiliency (e.g., Rad hard; no hysteresis; long MTBF)
  - Power handling capabilities (particularly for Tx arrays)

1. “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
2. “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.

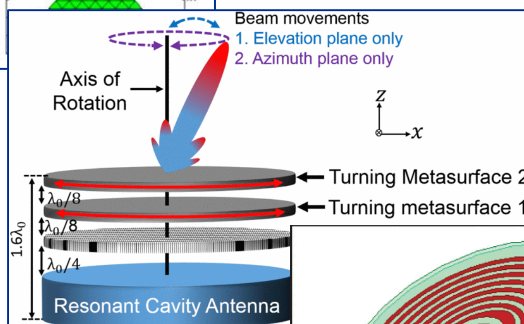
Reconfigurable Antennas

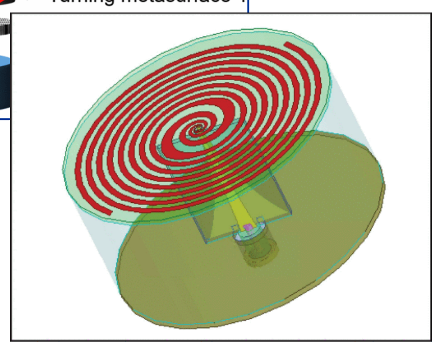
Example of Potential Reconfigurable and UWB Antennas

Fractal Antennas (Ref. 1)



Metasurface Based Antennas (Ref.2)





UWB Spiral Antenna (Ref. 3)

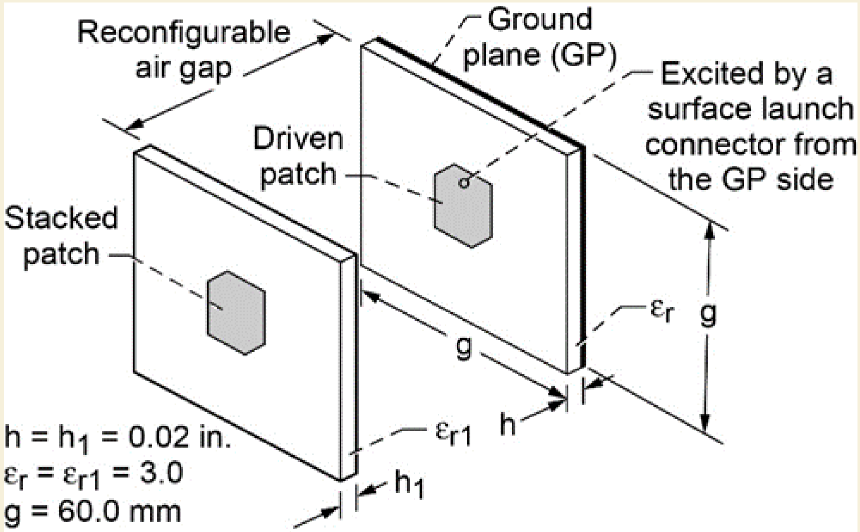
Potential Functions

- Ultra Wide Band
- Multi-Band
- Multi-function (Sensing and Communications)
- Beam shaping
- Beam steering

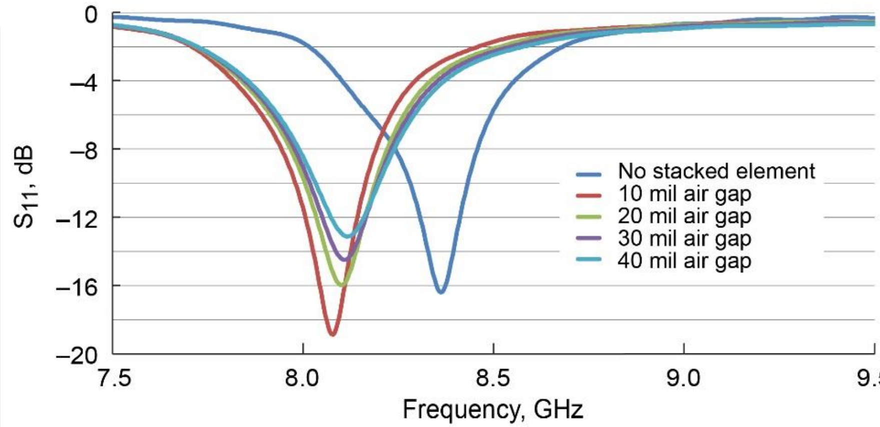
References:

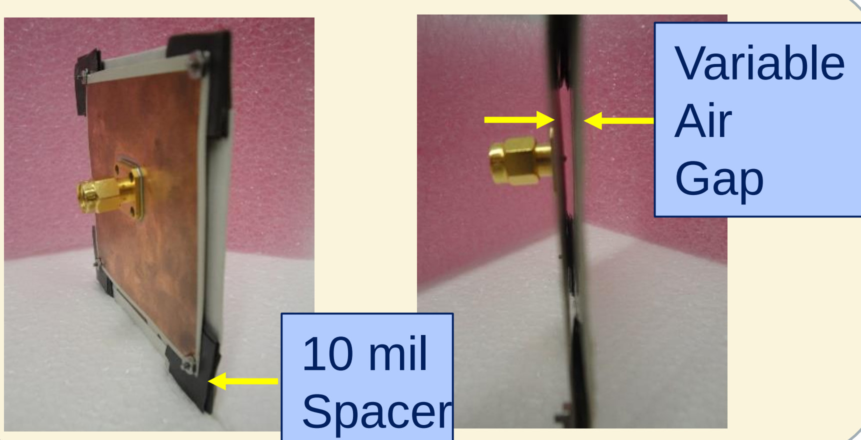
1. Jaspreet Kaur, Surjeet Singh and Ankush Kansal, 2011. Multiband Behavior of Sierpinski Fractal Antenna. *Research Journal of Information Technology, 3: 35-43.*
2. M. U. Afzal and K. P. Esselle, "Application of near-field phase transformation to steer the beam of high-gain antennas in two dimensions," *2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, San Diego, CA, 2017, pp. 1947-1948.
3. Yang Zhao and Weidong Hu, "Design of a UWB unidirectional radiation compound spiral antenna," *2015 IEEE 6th International Symposium on Microwave, Antenna, Propagation, and EMC Technologies (MAPE)*, Shanghai, 2015, pp. 158-161.

Frequency Reconfiguration – CP Stacked Square Patches Separated by a Variable Air Gap

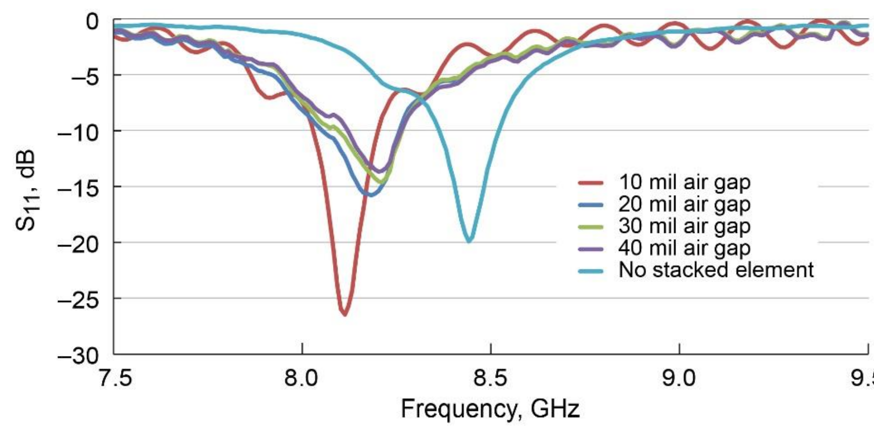


Simulated Results with Variable Air Gap





Measured Results with Variable Air Gap

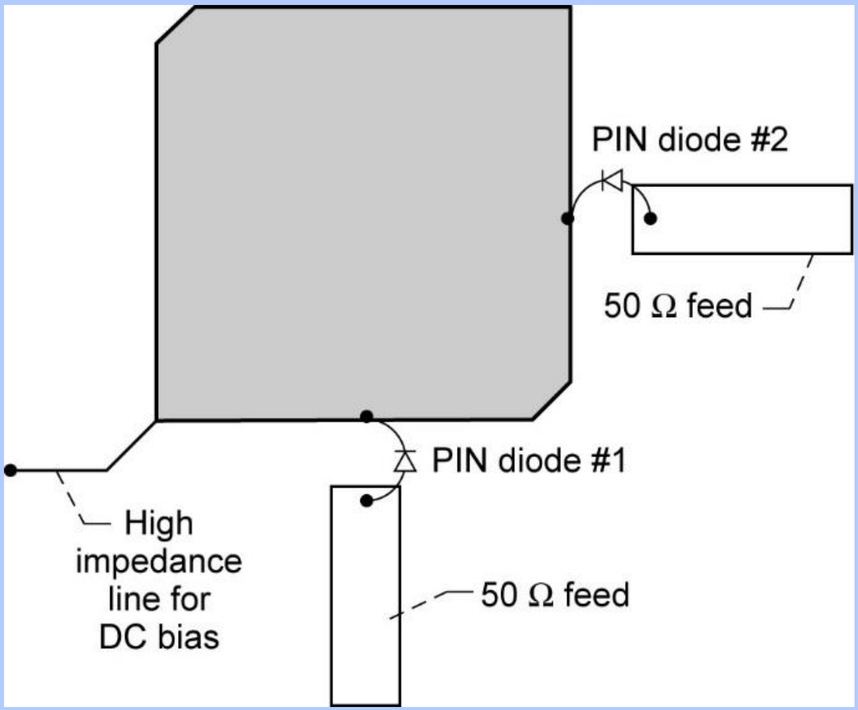


The central frequency in a stacked square patch can be reconfigured by as much as 100MHz (Shifted from 8.1017 to 8.2017 GHz)

Ref. M. Barbosa-Kortright, S. Waldstein, and R. Simons "**Reconfigurable Wideband Circularly Polarized Stacked Square Patch Antenna for Cognitive Radios,**" IEEE Cognitive Communications for Aerospace, June 28, 2017, Cleveland OH.

Polarization Reconfiguration – CP Square Patch

Corner Truncated Square Patch

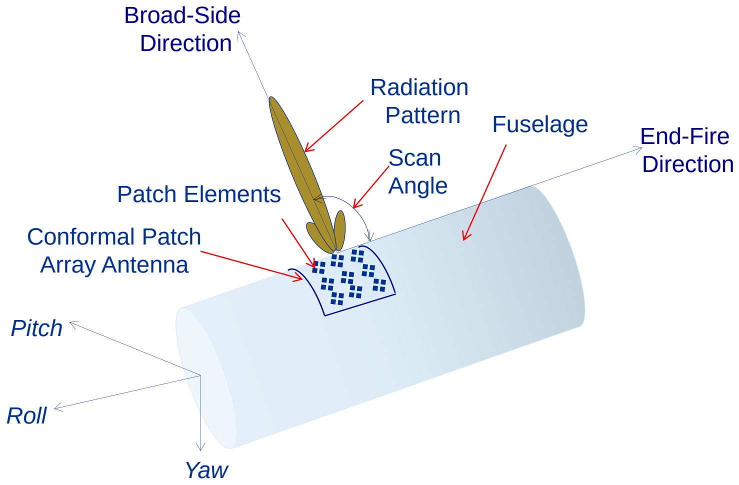


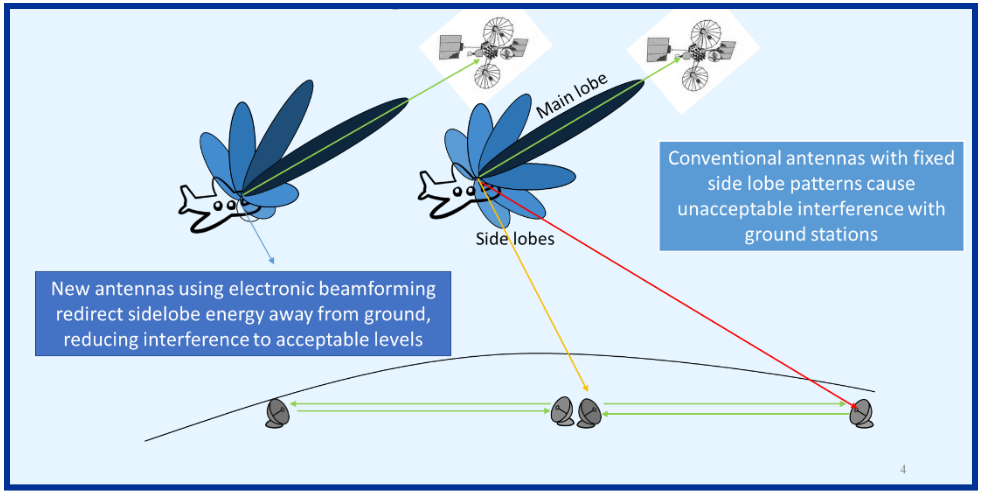
- **Polarization Reconfiguration:**
  - Demonstration of semiconductor control component integration with printed circuit antenna elements
  - Switching is performed by PIN diodes
  - Ability to reconfigure between LHCP or RHCP

Ref. M. Barbosa-Kortright, S. Waldstein, and R. Simons "**Reconfigurable Wideband Circularly Polarized Stacked Square Patch Antenna for Cognitive Radios,**" IEEE Cognitive Communications for Aerospace, June 28, 2017, Cleveland OH.

Conformal Lightweight Antenna Structures For Aeronautical Communications Technologies (CLAS-ACT)

Generic Conformal Phased Array



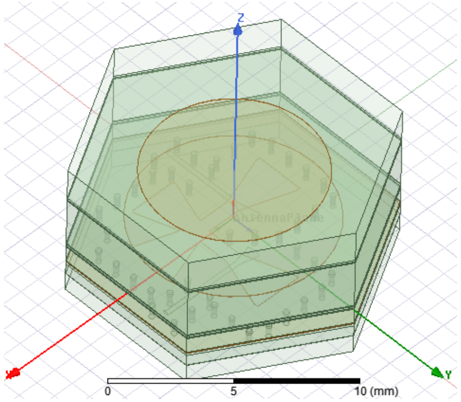


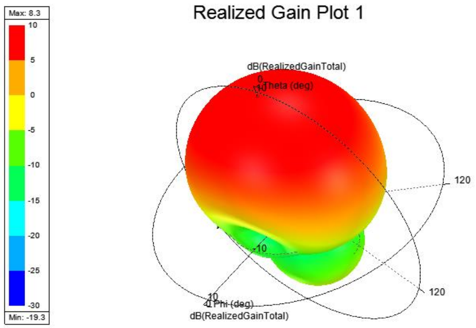
This project is to develop antennas which enable beyond line of sight (BLOS) command and control for UAVs. We will take advantage of newly assigned provisional Ku-bands for UAVs and use unique antenna designs to avoid interference with ground. This will involve designing antennas with high effective radiated power (EIRP) and ultra-low sidelobes. The antennas will be made with polymer aerogel as a substrate to both reduce weight and improve performance,

POCs: Dr. Mary Ann Meador (maryann.meador@nasa.gov); Dr. James Downey; Mr. Bryan Schoenholz; Ms. Marie Piasecki

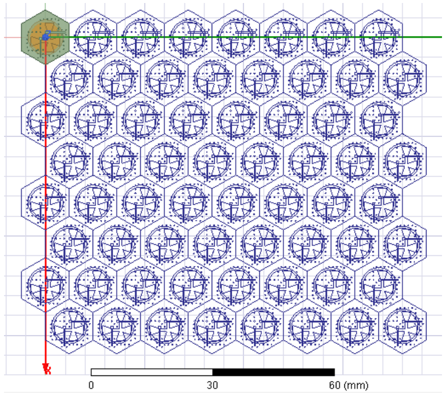
CLAS-ACT Antenna Design

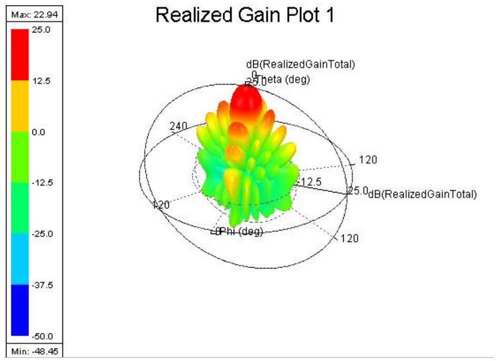
Circular Patch Element



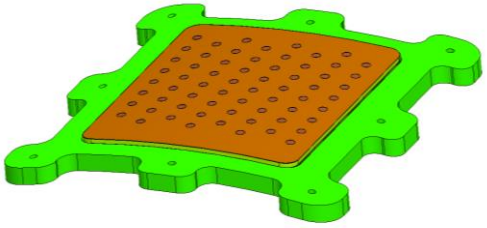


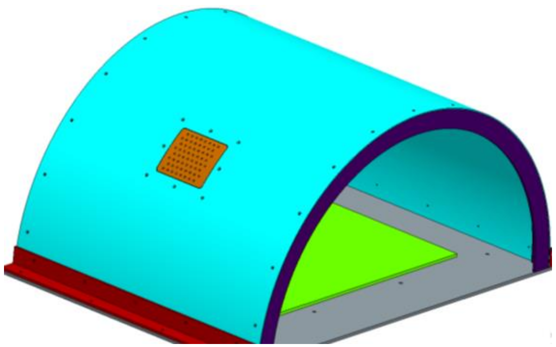
Triangular Lattice Sub-Array





Conformal Prototype Array for Flight Test

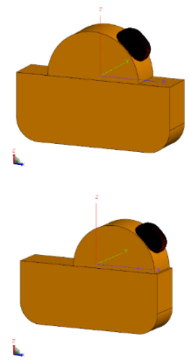


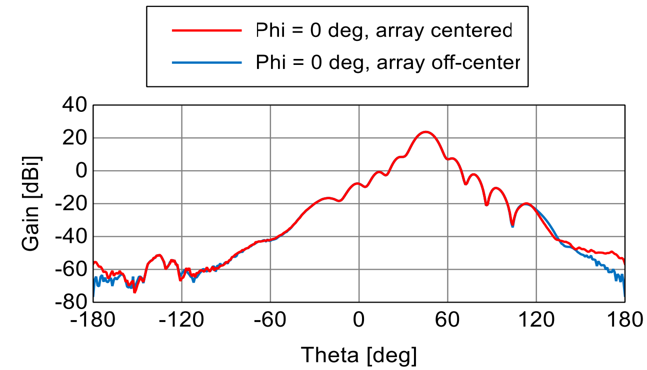


POCs: Dr. Mary Ann Meador (maryann.meador@nasa.gov); Dr. James Downey; Mr. Bryan Schoenholz; Ms. Marie Piasecki

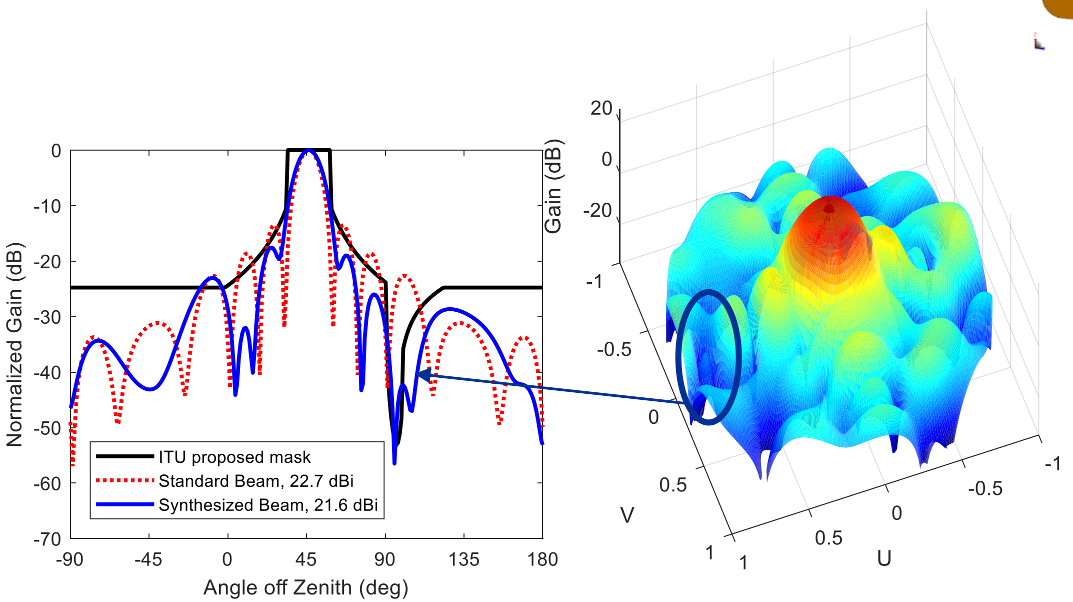
Antenna Pattern Simulations

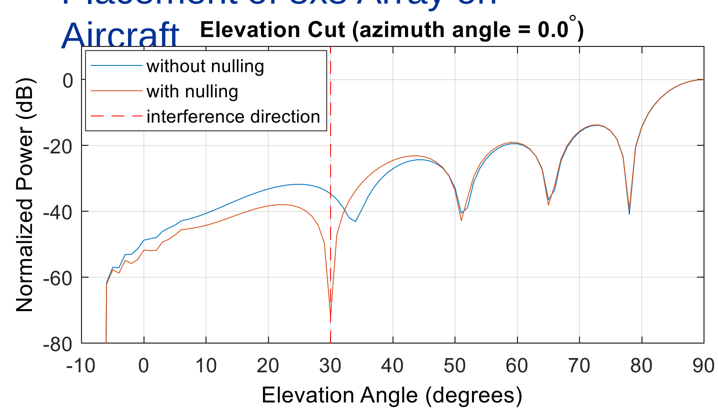
- Simulated performance of 64 element sub-array
  - Conformed to 16” radius
  - Antenna-aircraft coupling effects
  - Beam synthesis (alternating projections with quantization) and null steering methods to meet ITU mask





Placement of 8x8 Array on Aircraft



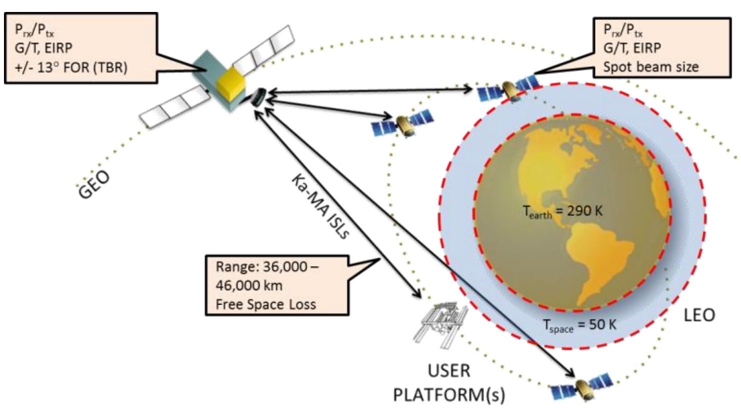


Null Steering of 8x8 Array

POCs: Dr. Mary Ann Meador (maryann.meador@nasa.gov); Dr. James Downey; Mr. Bryan Schoenholz; Ms. Marie Piasecki

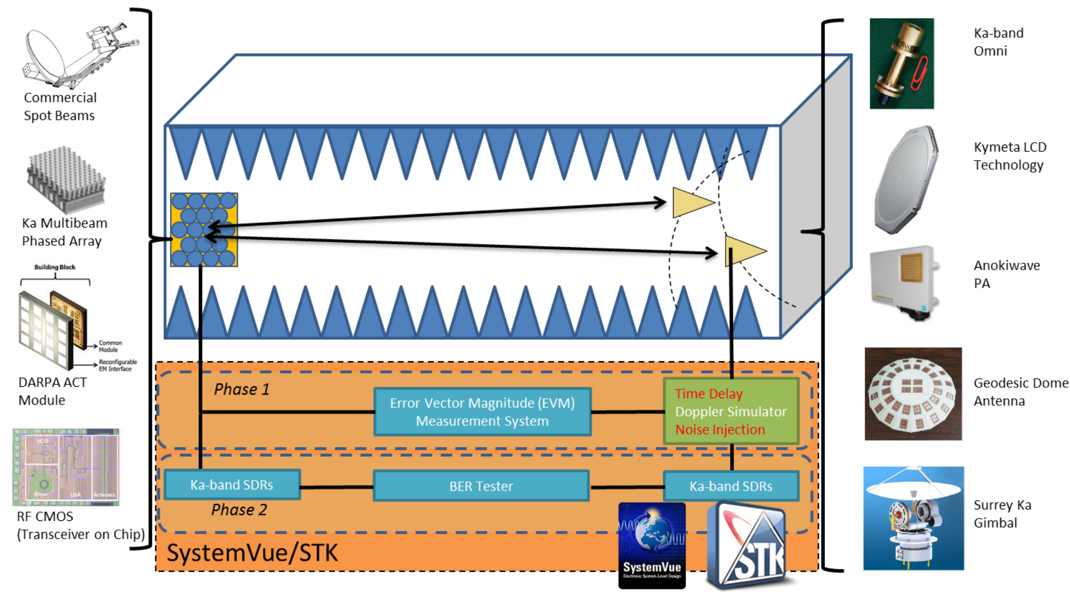
THE MULTIPLE ACCESS TESTBED FOR RESEARCH IN INNOVATIVE COMMUNICATIONS SYSTEMS (MATRICS)

GRC Test Bed to Evaluate Antenna Performance in a Controlled Emulated Environment



TDRSS Ka Forward Service	
EIRP	63 dBW
Free Space Loss	~210 dB
Bandwidth	50 MHz
Modulation	BPSK/UQPSK
Data Rate	300 kbps – 25 Mbps
Max. User Rx Power (before antenna)	-117 dBm

TDRSS Ka Return Service	
G/T	26.5 dB/K
Free Space Loss	~210 dB
Bandwidth	225 - 650 MHz
Modulation	BPSK/UQPSK
Data Rate	300 Mbps

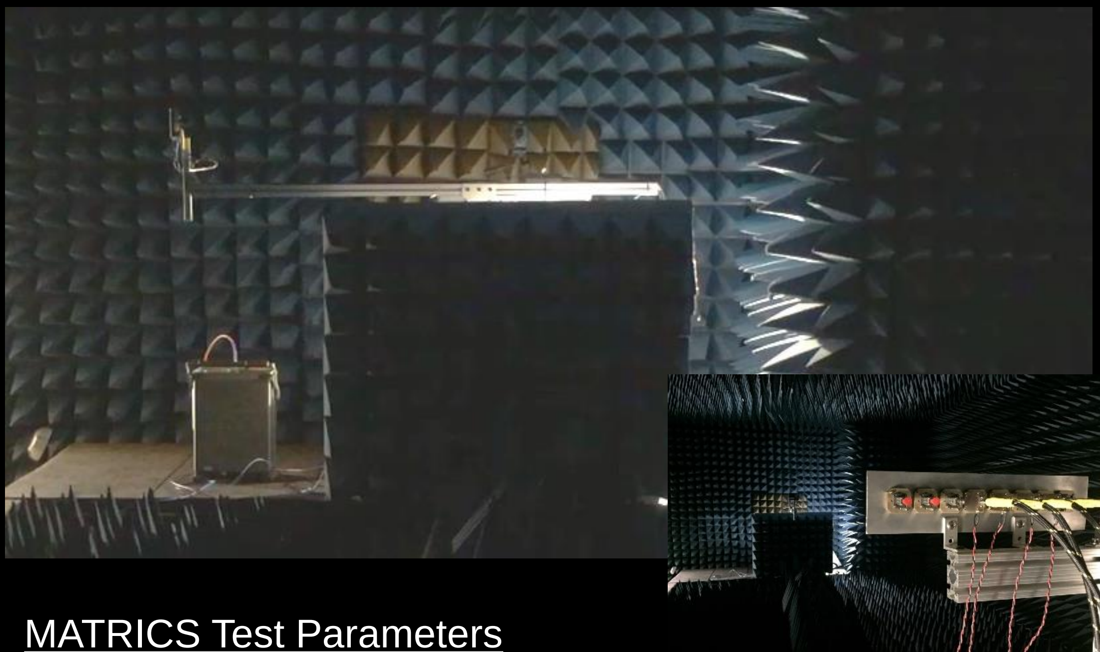


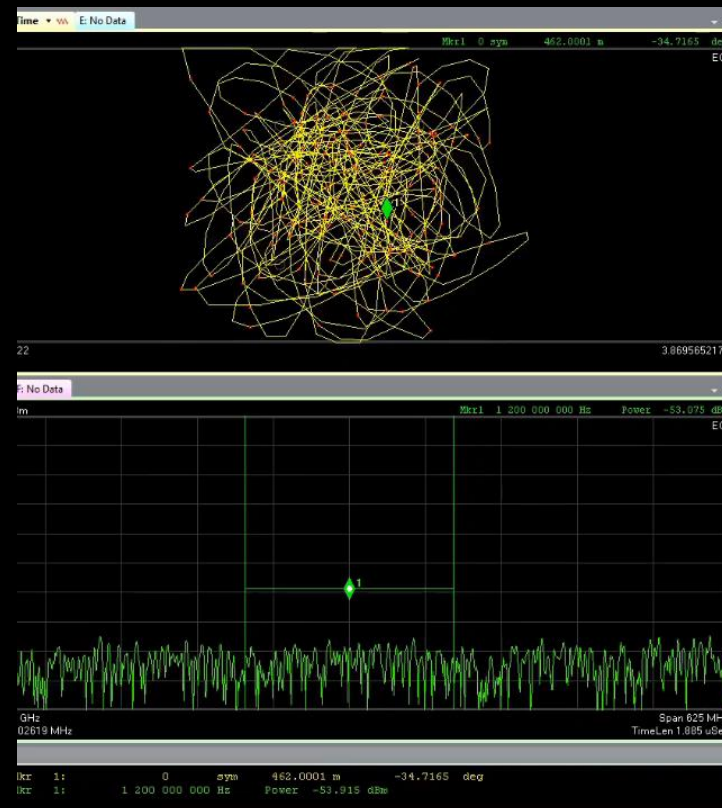
- **Approach**: *Scale LEO-GEO relay links into a controlled, emulated environment to perform CONOPS, architecture trades, and technology assessments for various relay/user terminal technologies.*
- Flexible platform to test/demonstrate various relay and user terminal technologies and CONOPS

GRC POC: Dr. James Nessel (james.a.nessel@nasa.gov)

The MATRICS

Dynamic Phased Array Testing





MATRICS Test Parameters

- ISS LEO orbit configuration
- Anokiwave 64-element COTS phased array
- 26 GHz return service link
- Characterize EVM through entire LEO-GEO link pass

GRC POC: Dr. James Nessel (james.a.nessel@nasa.gov)

Summary and Conclusions

- Reconfiguration of communication systems is critical to maximize the performance of communication assets particularly those in aerospace applications where,
  - Assets are difficult to reach for replacement and/or maintenance (i.e., space)
  - Assets as limited to small form factors and conformal surface (e.g., Space CubeSats and aerospace platforms such as UAVs, sUAS, and HALE among others.
- System reconfiguration has been demonstrated in space via Software Define Radio (SDR). GRC has led numerous experiments since 2012 up to present suing the Space Communications and Navigation (SCaN) Test bed in the International Space Station.
- Yet, SDR reconfiguration is based on-command based (i.e., Human-Machine interface which becomes more challenging for Deep Space Communications.
- Cognitive Communications Systems could potentially address autonomous reconfiguration on demand.
- Accordingly, hardware that is reconfigurable is required to fully exploit the potential of cognitive communications systems.
- Reconfigurable antennas and cognitive antennas are then critical technologies highly desired for the next generation of aerospace communications architecture.