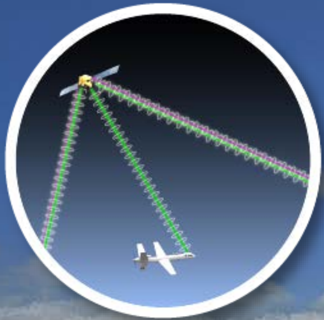

Phased Array Antenna for the Mitigation of UAS Interference

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Phased Array Antenna for UAS Interference

Introduction

Integration of UAS into non-segregated airspace requires very high performance Command and Control (C2) communications

Protected aviation spectrum, or functionally equivalent, is required by ICAO

For Radio line-of-sight (LOS) using terrestrial systems (air-to-ground)

Beyond radio line-of-sight (BLOS) can be achieved with:

- Networked terrestrial stations
- Satellite communications for oceanic, remote, or where terrestrial systems do not provide adequate coverages, or where an independent redundant system is required to achieve very high C2 availability

New satellite bands were provisionally allocated at WRC-15 Satellite Communications

Meeting interference criteria (UAS into co-primary terrestrial systems) will be very difficult

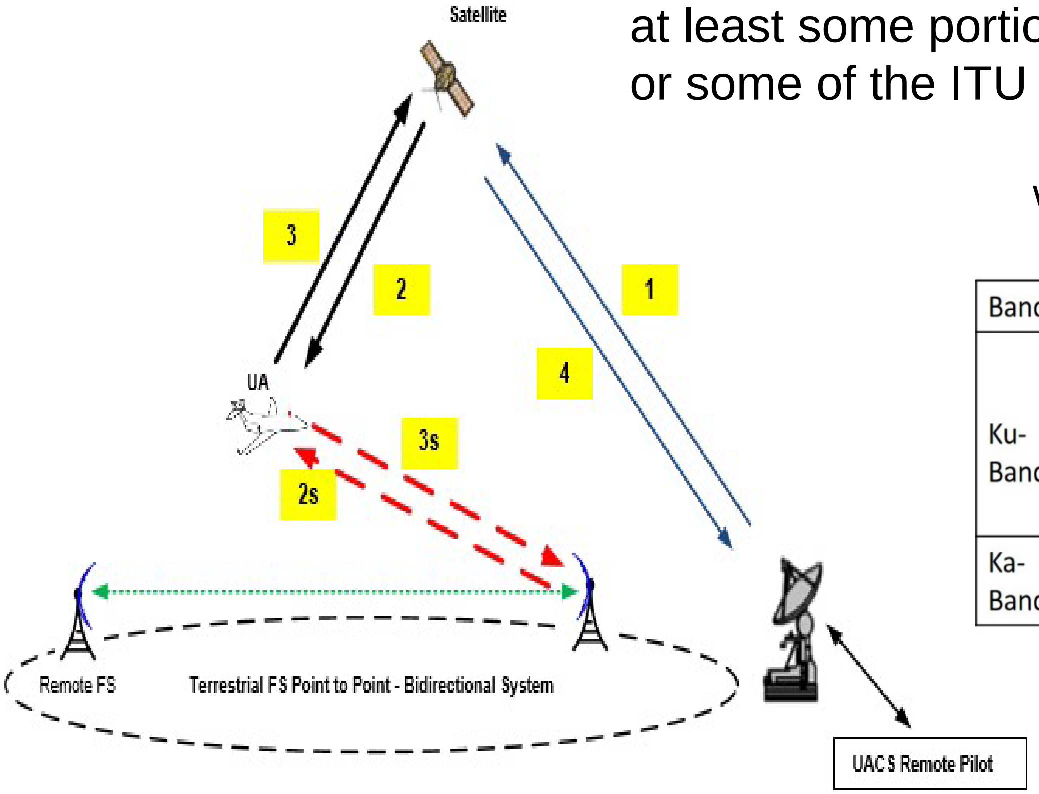
Phased array antenna may provide a solution

New, lightweight, conformal phased array antenna is being developed and tested for this application

Regulatory Aspects of Satellite UAS C2

UAS to FS Interference Environment

In all of the Ku Band allocations there are co-primary Fixed Service (FS) allocations covering at least some portions of these allocations in all or some of the ITU Regions



WRC-15 Allocations for UAS C2 in the Fixed Satellite Service

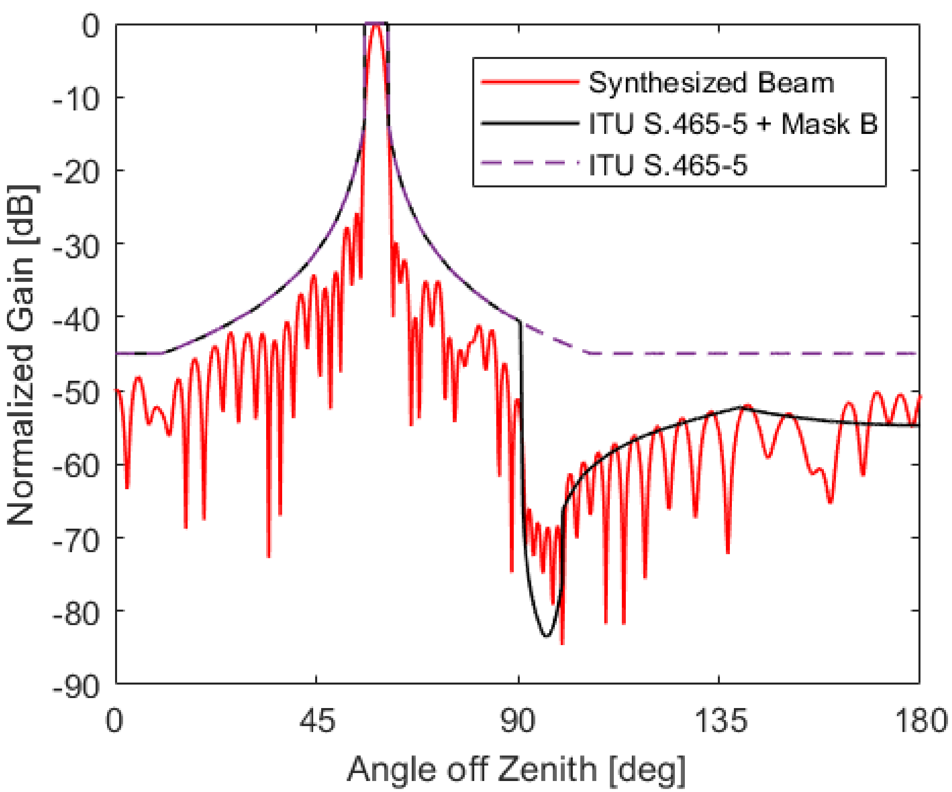
Band	Space-to-earth	Earth-to-space
Ku-Band	10.95-11.2 GHz	14-14.47 GHz
	11.45-11.7 GHz	
	11.7-12.2 GHz (ITU Region 2)	
	12.5-12.75 GHz (ITU Region 1,3)	
Ka-Band	19.7-20.2 GHz	29.5-30.0 GHz

Links 2s/3s represent potential interference through antenna sidelobes.

Beam Steering to Mitigate Interference

Potential phased array antenna shows how the PFD requirement can be met

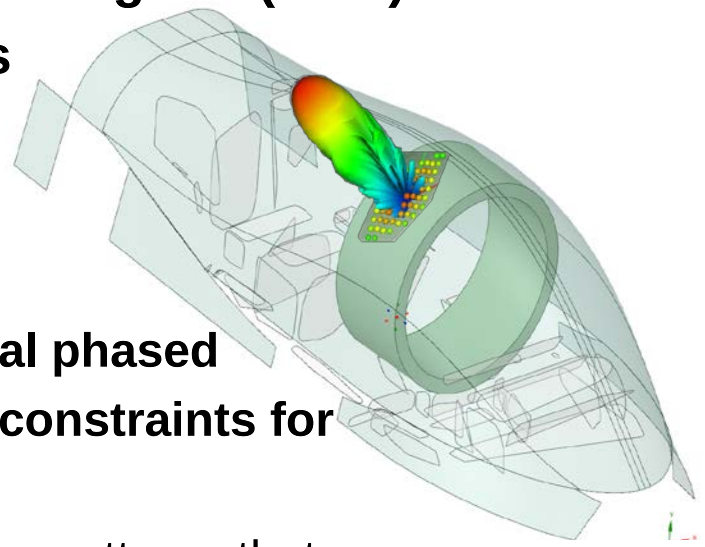
- A beam synthesis technique shows that a synthesized pattern approaches the desired mask
- ~30 dB better than an S.465-5 antenna in the 90-100° region of the pattern



Antenna Mask Requirements Compared to Synthesized Phased Array Pattern using method of alternating projections

CAS CLAS-ACT Project

NASA's Convergent Aeronautics Solutions Program (CAS)
Conformal Lightweight Antenna Structures
for Aeronautical Communications
Technologies (CLAS-ACT)



CLAS-ACT is developing a lightweight conformal phased array antenna to help address the difficult PFD constraints for Ku Band UAS C2

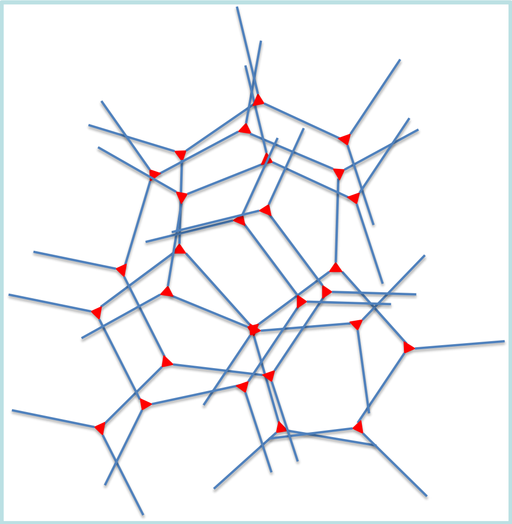
- Use null-steering/beam synthesis to form antenna patterns that are otherwise difficult to realize with traditional antenna designs

Apply a novel flexible polyimide aerogel as the antenna substrate

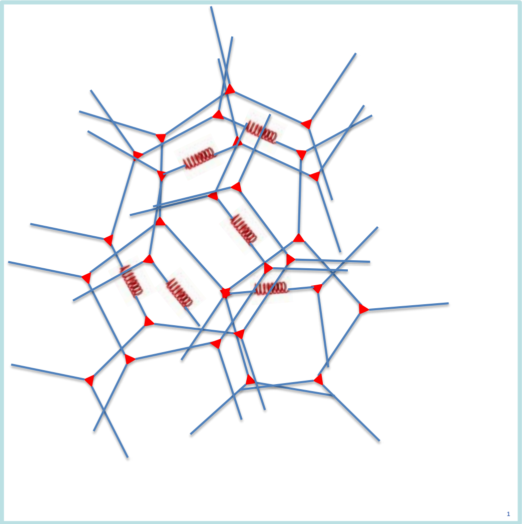
- Aerogels are 90% air leading to much lower weight and potential for improved antenna characteristics (e.g. bandwidth and gain)
- Arrays can be thin, flexible and conformal – greatly reducing weight and aerodynamic drag
- Can enable BLOS for smaller UAS platform that are too small for conventional satellite antennas

Aerogel Substrate

- **Aerogels are light weight with low dielectric constant**
- **Adding flexibility enables the conformal array while reducing weight**



Rigid polymer backbone



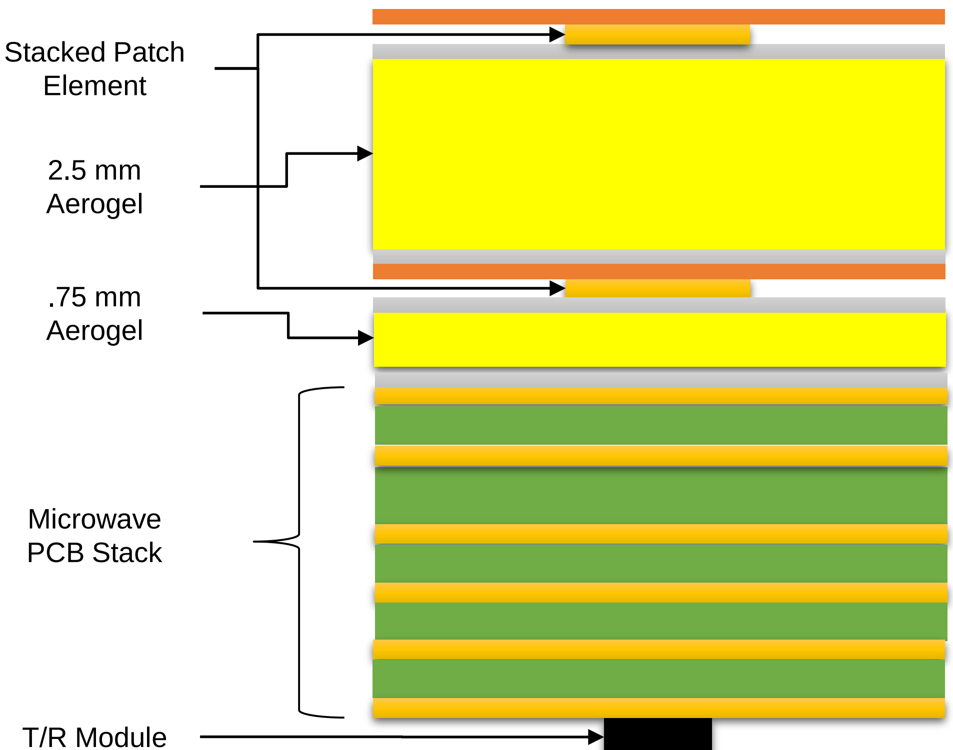
25 to 75 % flexible links included in polymer backbone

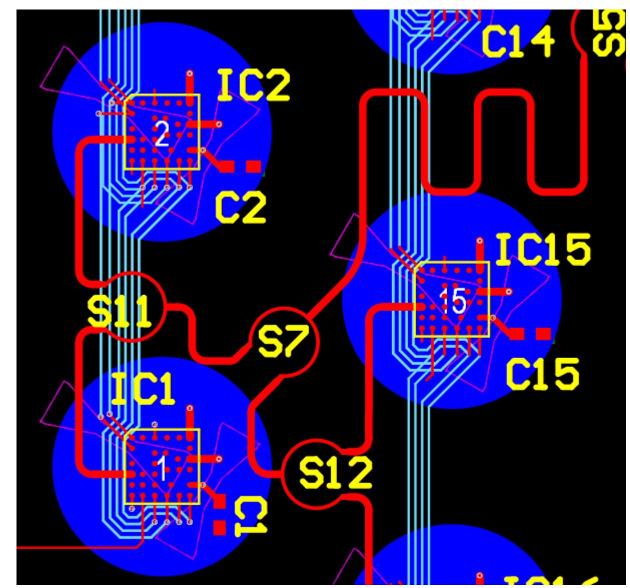
25 % of rigid links replaced by flexible links

Lightweight Conformal Phased Array Development

Phased array composition

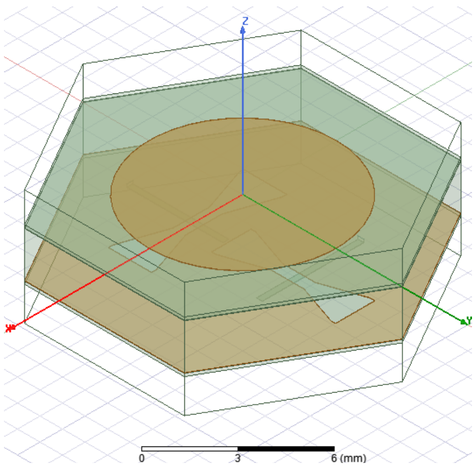
- A relatively thick flexible aerogel layer (~2 mm) maximizes the benefits of the low dielectric constant for efficient radiation
- Thin multi-layer stack of higher dielectric materials for the feed network
- 50 % mass savings
- Commercially available transmit/receive (TR) chip modules provide electronic weighting of each element

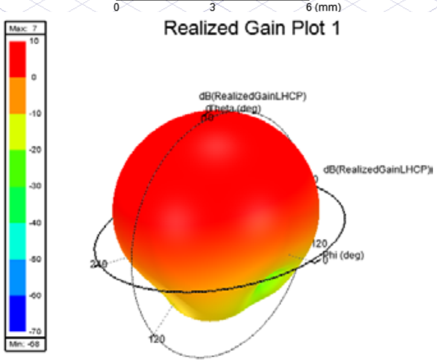




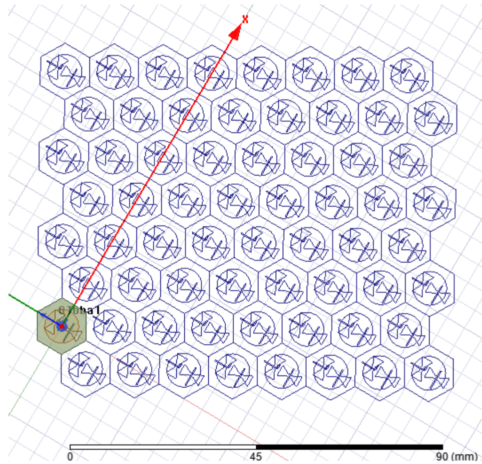
Antenna Design

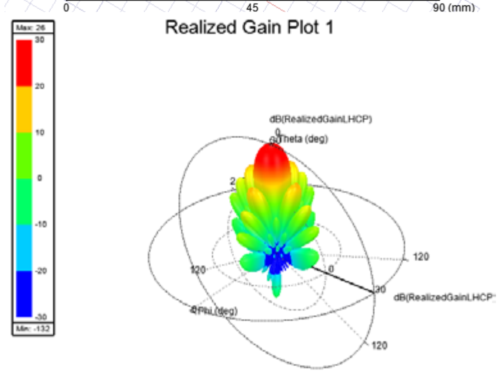
Circular Patch Element



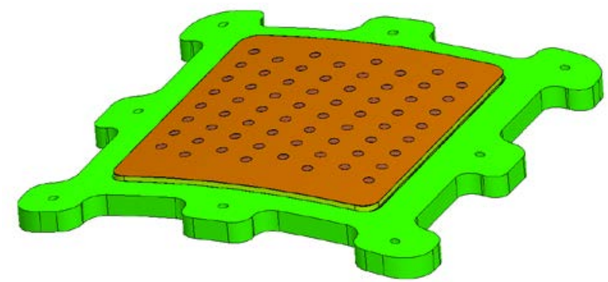


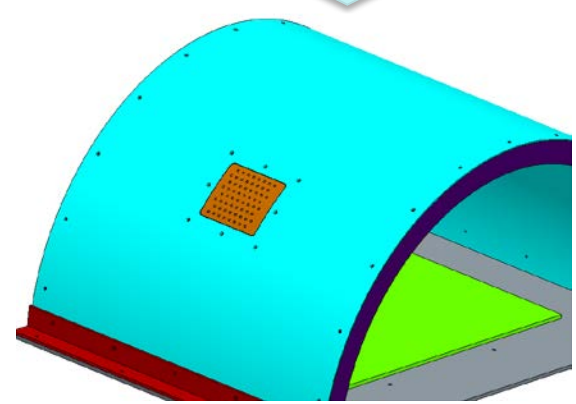
Triangular Lattice Sub-Array



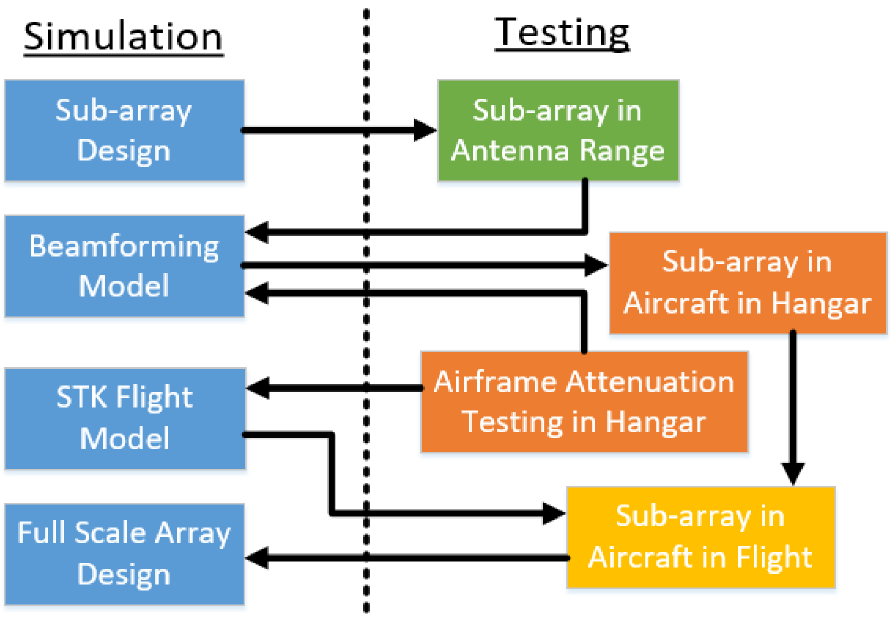


Conformal Prototype Array for Flight Test





Planned Testing of the CLAS-ACT Prototype Subarray



Array Simulation and Testing Flow Diagram

Antenna Range testing

- Capture the expected performance of the array including gain and beam steering pattern

Hanger Testing on a UAS

- Capture installed antenna performance, including fuselage/radome attenuation effects

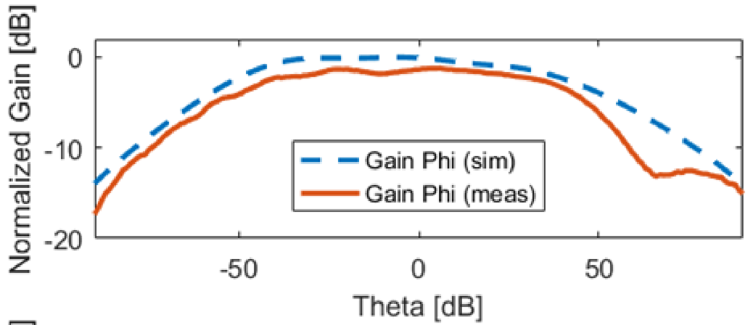
Flight testing on a UAS

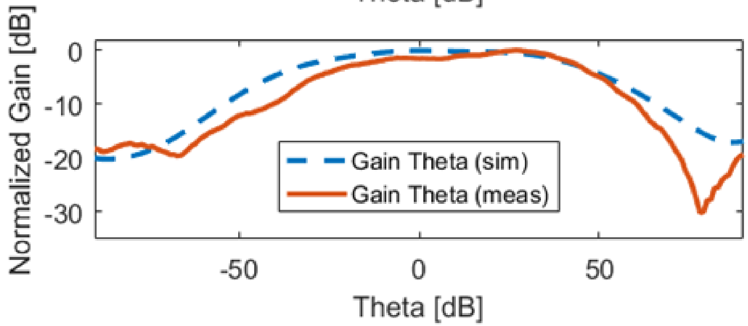
- Capture antenna array performance and ground interference at low elevation angles (5º to 25º) during a UAS flight

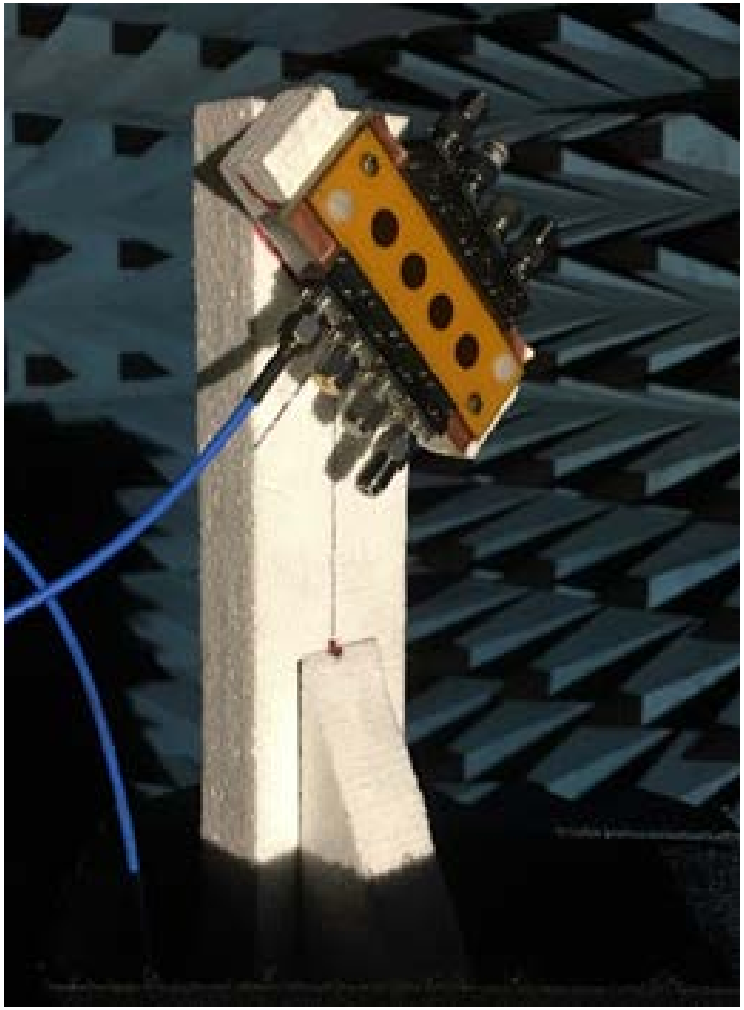
Lightweight Conformal Phased Array Development

4-element Array Testing

- A test array was built to verify simulation fidelity and fabrication techniques
- A technique to align and bond the aerogel substrate with the radiating elements as well as a microstrip feed layer
- This array is currently undergoing testing in an anechoic chamber at NASA Glenn Research Center



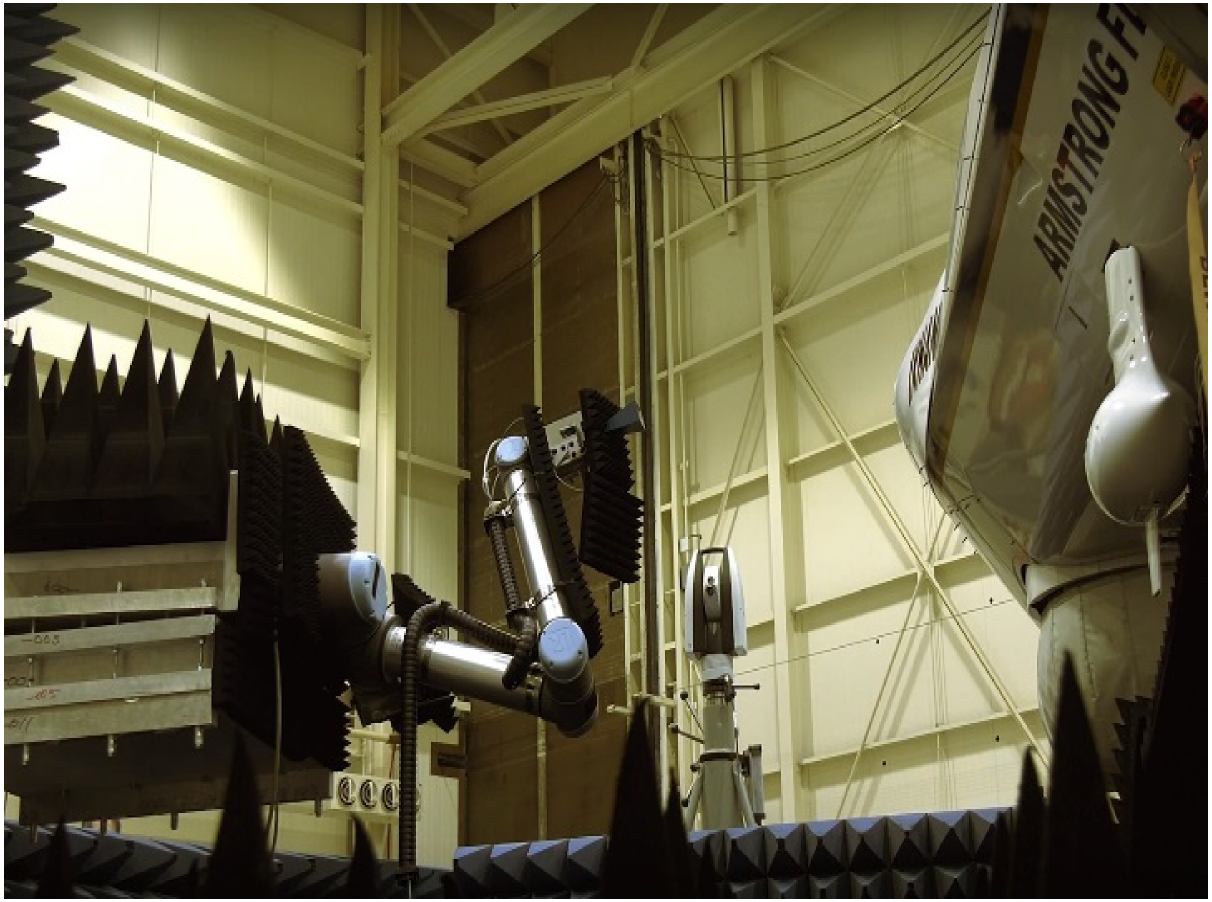




Planned Testing of the CLAS-ACT Prototype Subarray

Hanger Testing on a UAS

The system uses a robotic arm mounted on a mobile base along with a laser tracker for precise positioning around a device under test

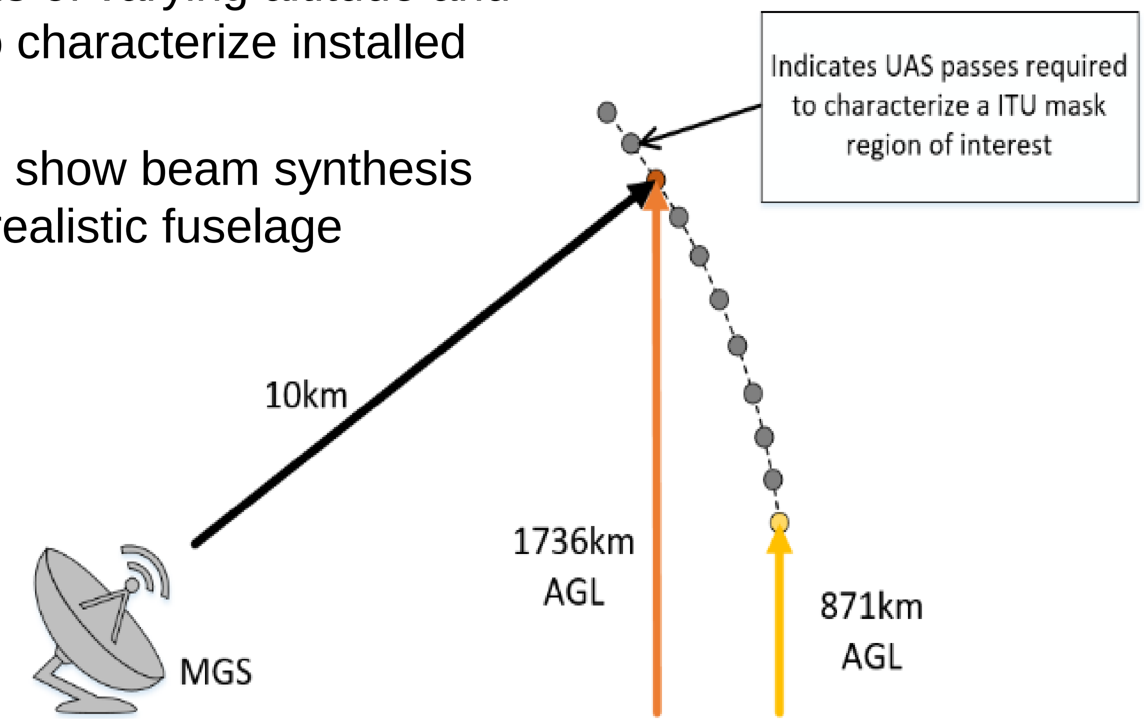


Planned Testing of the CLAS-ACT Prototype Subarray

Flight Testing on a UAS

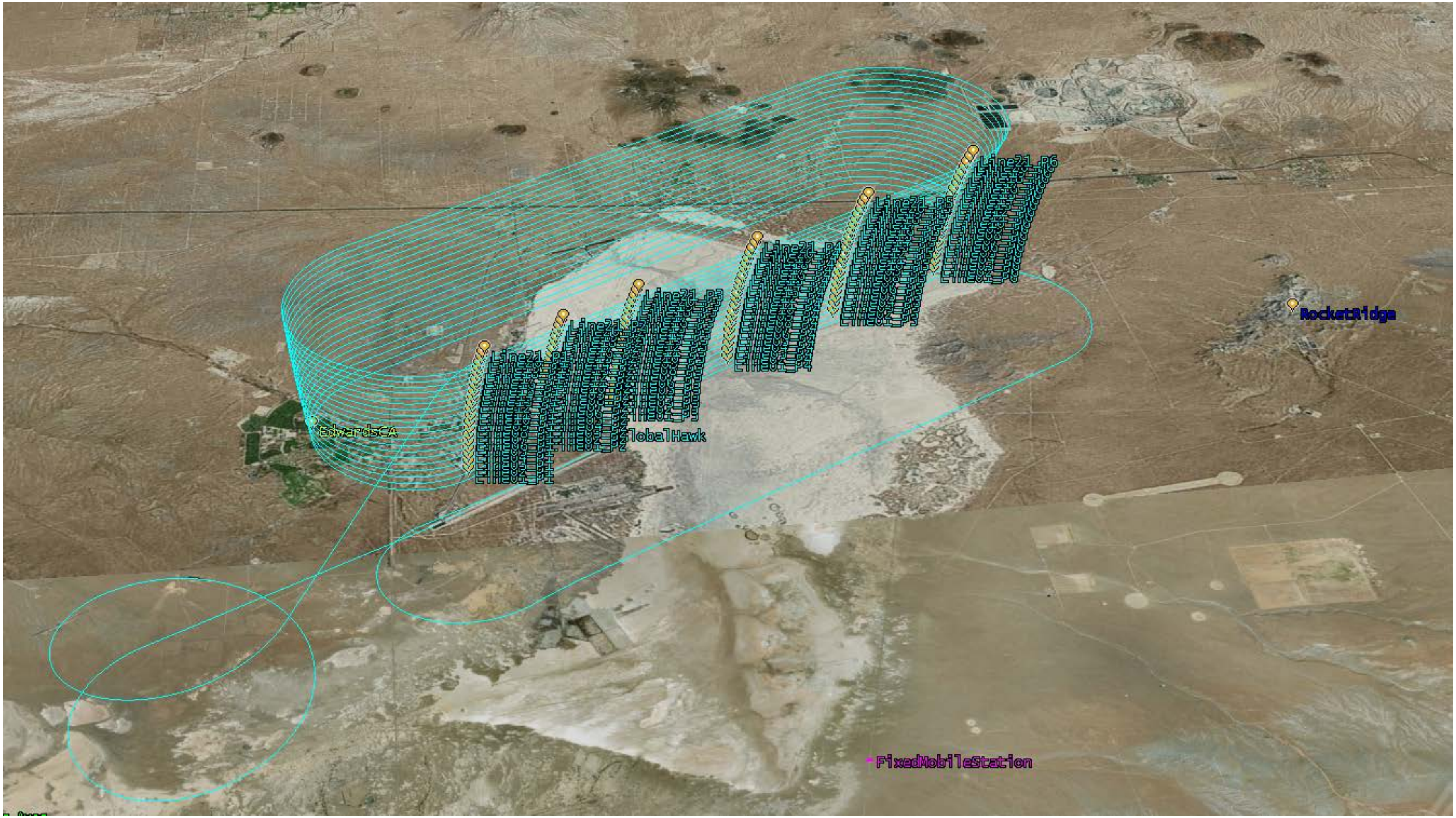
A measurement ground station (MGS) will capture antenna array performance and ground interference at low elevation angles (5º to 25º) during a UAS flight

- Aircraft will fly paths of varying altitude and ~constant range to characterize installed antenna pattern
- Measurements will show beam synthesis performance with realistic fuselage interactions



Example Flight Passes for Measuring a Region of the Antenna Pattern

Isometric View of Composite Passes



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Thank you!

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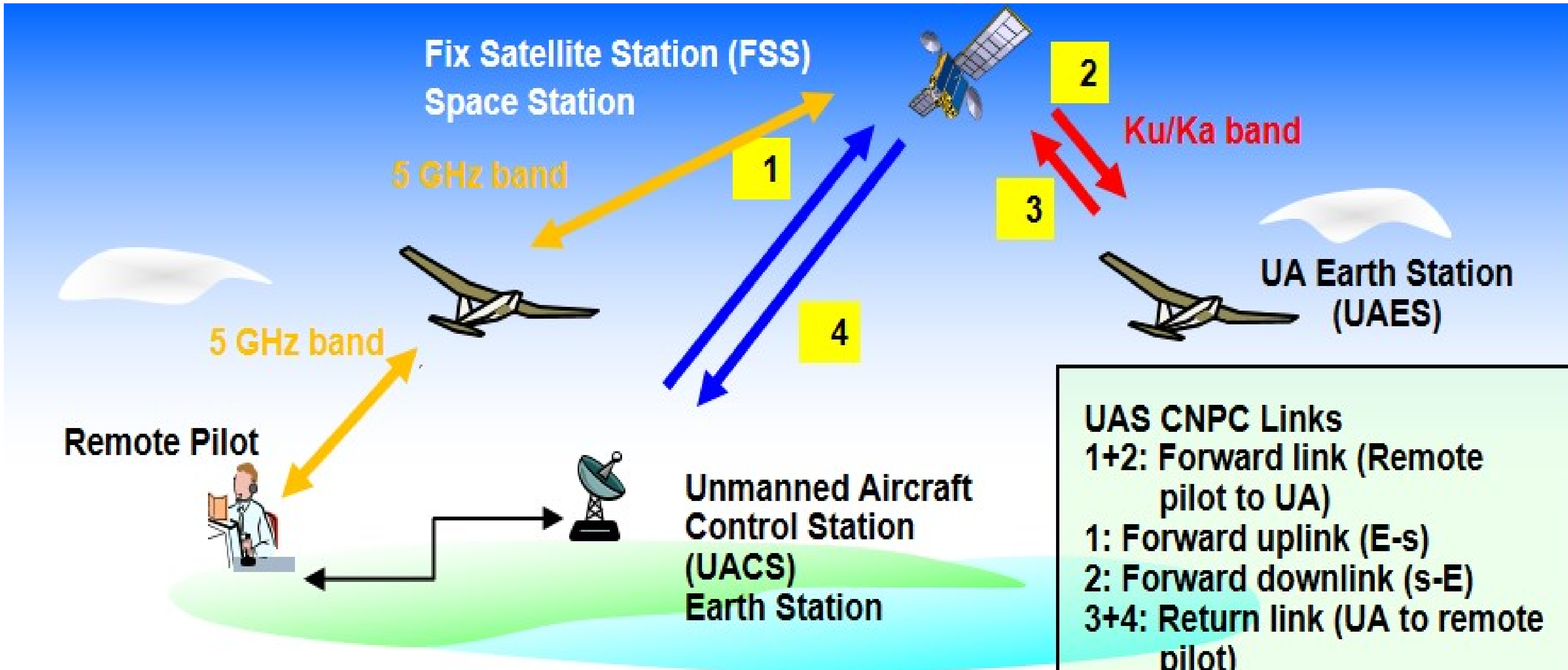
NASA Glenn Research Center

SatCom for BLOS UAS C2 Links

Unmanned Aircraft Systems and Command and Control Links



- Terrestrial C2 - 5030-5091 MHz
- Satellite communications C2
  - 5030-5091 MHz (no satellites exist)
  - Ku Band (11/14 GHz) – many Commercial FSS
  - Ka Band (20/30 GHz) – some Commercial FSS

Regulatory Aspects of Satellite UAS C2

World Radiocommunication Conference (WRC-15) Resolution 155 established Fixed Satellite Service (FSS) bands to support UAS C2

FSS is not an aviation safety service, so to carry UAS C2 links these FSS systems must meet an equivalent level of service, meeting conditions defined by ICAO

Resolution 155 has other requirements:

Can only use FSS networks that have been successfully coordinated and have been notified and recorded in the Master International Frequency Register with favorable finding

- ICAO must complete Standards and Recommended Practices (SARPs)
- UAS SatCom receivers must accept interference from incumbent in-band co-primary services, in particular from Fixed Service (FS) transmissions
- UAS SatCom transmitters cannot cause harmful interference to FS receivers

UAS transmitters cannot exceed a power flux density (PFD) limit

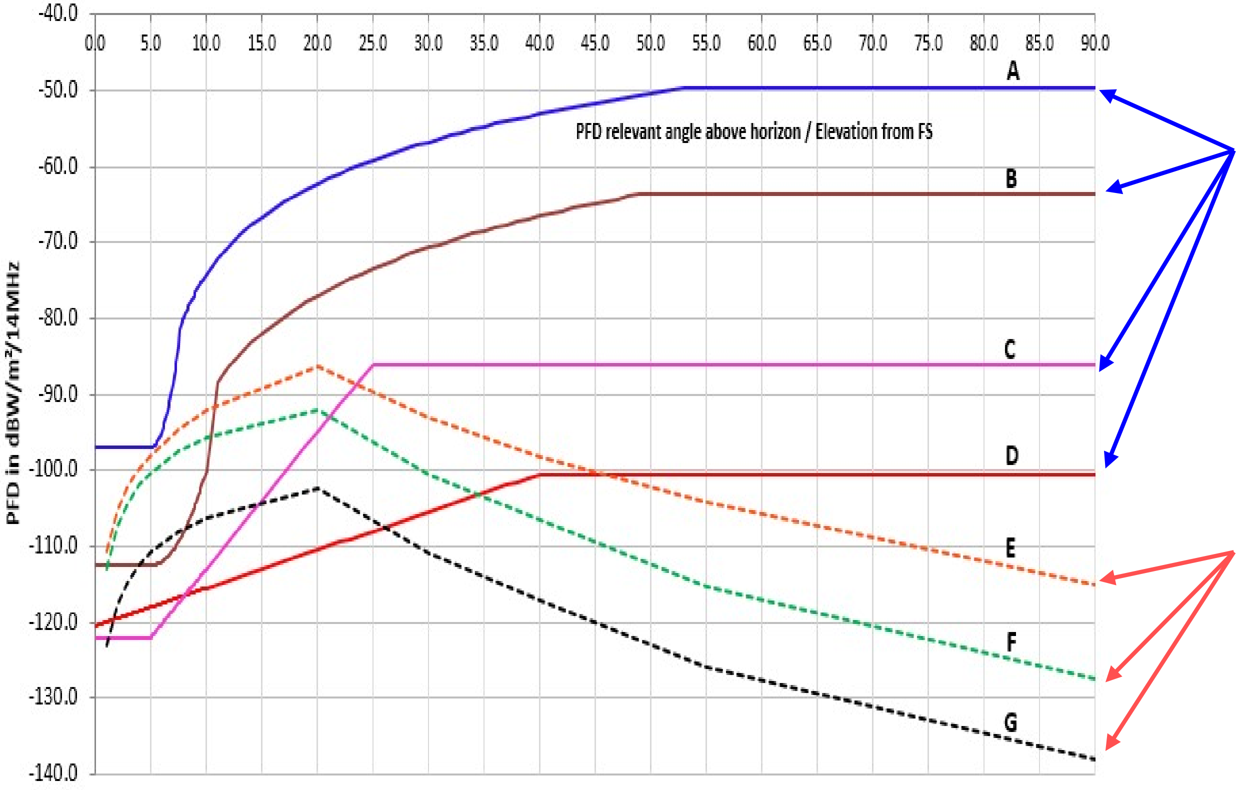
The PFD limit will be finalized at WRC-19

Some previously proposed pfd limits,
and projected UA emissions

PFD Limits

The final form of PFD limits to be applied to UAS transmitters is still being investigated in preparation for WRC-19

It remains a contentious issue among a small number of administrations



Proposed PFD limits (C is the most recent proposal)

Calculated UAS transmitted PFD using conventional ITU defined antennas and fuselage attenuation model included

- 51º latitude
- E and F 3000 ft altitude
- G 10000 ft altitude

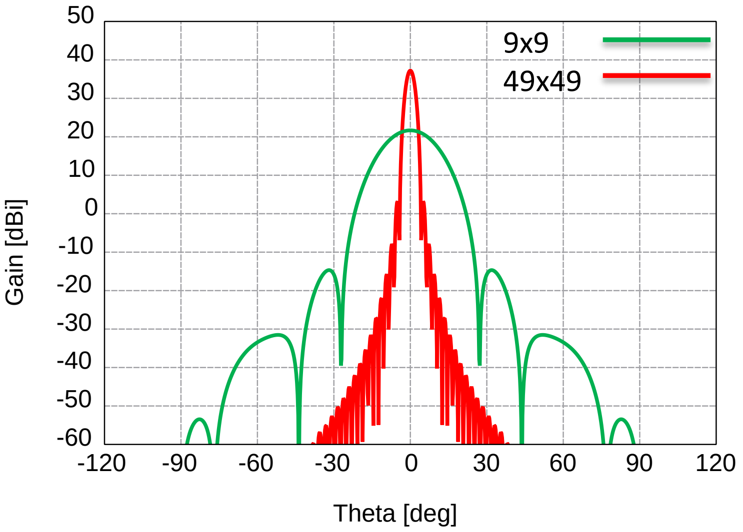
Lightweight Conformal Phased Array Development

CLAS-ACT is developing a sub-scale 64-element prototype phased array

- Explore the potential of flexible polyimide aerogels and phased array technology to address regulatory constraints and SWaP
- 64 elements is expected to be sufficient to demonstrate capability and scalability
  - Reduced risk of building and testing 1k+ element array in a short timeframe

Array to sub-array Scaling

- Gain patterns for 9x9 and 49x49 planar array
- Max gain is proportional to number of elements
- Peak to 1st sidelobe level is similar (aperture theory)



Phased Array Antenna for UAS Interference

Summary

WRC-15 provisionally approved the use of Ku-band satcom links for UAS C2 communications

However, to protect co-primary incumbent terrestrial services, a PFD limit on UAS transmissions will be imposed

- The PFD limit is expected to be severely constraining and will limit UAS operations

To overcome this constraint, the CLAS-ACT Project is developing and testing a novel conformal phased array antenna

- Exploit beam synthesis and null steering techniques to reduce the UAS PFD acceptable levels, enabling UAS to operate constraint-free while protecting the terrestrial services
- Antenna design will leverage the use of a novel, ultra-lightweight aerogel material to provide a high performance and low SWaP solution
- This low SWaP design may enable smaller UAS to gain BLOS coverage

Antenna designs, initial performance measurements, and preliminary aircraft ground measurements have been completed