Phased Array Antenna for the Mitigation of UAS Interference

James M. Downey, Bryan L. Schoenholz
Marie T. Piasecki, Robert J. Kerczewski
NASA Glenn Research Center, Cleveland, Ohio, USA

Presented by:
Bob Kerczewski
NASA Glenn Research Center

2018 ICNS Conference – 10-12 April 2018
OUTLINE

• Introduction
• Satellite Communications for BLOS UAS C2 Links
• Regulatory Aspects of Satellite UAS BLOS C2 Communications
• CAS CLAS-ACT Project Description
• Lightweight Conformal Phased Array Development
• Planned Testing of the CLAS-ACT Prototype Subarray
• Summary
Integration of UAS into non-segregated airspace requires very high performance Command and Control (C2) communications

- Protected aviation spectrum, or functionally equivalent, required by ICAO
- Radio line-of-sight (LOS) using terrestrial systems (air-to-ground)
- Beyond radio line-of-sight (BLOS) using:
  - Networked terrestrial stations
  - Satellite communications – 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**

- But 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**
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

UAS CNPC Links
1+2: Forward link (Remote pilot to UA)
1: Forward uplink (E-s)
2: Forward downlink (s-E)
3+4: Return link (UA to remote pilot)
3: Return uplink (E-s)
4: Return downlink (s-E)
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
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

<table>
<thead>
<tr>
<th>Band</th>
<th>Space-to-earth</th>
<th>Earth-to-space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ku-Band</td>
<td>10.95-11.2 GHz</td>
<td>14-14.47 GHz</td>
</tr>
<tr>
<td></td>
<td>11.45-11.7 GHz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.7-12.2 GHz (ITU Region 2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.5-12.75 GHz (ITU Region 1,3)</td>
<td></td>
</tr>
<tr>
<td>Ka-Band</td>
<td>19.7-20.2 GHz</td>
<td>29.5-30.0 GHz</td>
</tr>
</tbody>
</table>

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

- 51° latitude
- E and F 3000 ft altitude
- G 10000 ft altitude
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
Potential performance of CLAS-ACT 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
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 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
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
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 (5° to 25°) during a UAS flight
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.
Flight Testing on a UAS

A measurement ground station (MGS) will capture antenna array performance and ground interference at low elevation angles (5° to 25°) 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
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
Acknowledgments

The authors wish to thank:

Dr. Mary Ann Meador’s aerogel team and Liz McQuaid of NASA Glenn Research Center, Dr. Kevin Lambert of Vantage Partners LLC, and the NASA Armstrong Flight Research Center Ikhana Ops crew for their contributions to this effort.

William D. Bishop of Jacobs Engineering for graphics developed for this paper.
Phased Array Antenna for UAS Interference

Thank you!

For further information contact:

James M. Downey
James.m.downey@nasa.gov

NASA Glenn Research Center