A CubeSat Mission for Locating and Mapping Spot Beams of GEO Comm-Satellites

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Outline

- Background & Motivation
- Spot Beam Mapping Mission + OV-1
- Design of Mission Model
- Software Tools
- Developed Simulations & Results
- Features of Operation
- Conclusion / Future Work
Radio Frequency domain verification from GEO… tied with small satellite mission development concepts

-- Future space environment
  - Increased congestion
  - Increasingly contested
  - Increasingly competitive

  Especially at GEO!

-- GEO Spot beam mapping
  - Analogous constellation-based RF collection missions
  - Enhance RF domain knowledge
  - Identify coverage areas

-- Small Satellites (i.e. disaggregation)
  - May reduce costs vs. larger space missions
  - Maturing technology increases viability
  - Missions include common features / architectures
Motivation
Spot Beam Mapping CubeSat

--- AFIT CubeSat Research
- Mission Analysis and Payload/Bus Design
- Satellite Design and Test Sequence (6U CubeSat)
  1) Systems Engineering
  2) Spacecraft Analysis & Design
  3) Spacecraft Build & Test

--- RF Domain Verification / Analysis
- Identify spot beam locations (space-ground links)
- Manage frequency allocations (avoid interference)
- Improve ground trace knowledge
  • Increase link efficiency
  • Identify areas of poor signal coverage

**Key Focus:** Is it possible to effectively map spot beams coming from GEO Comm-Satellites using a CubeSat constellation?
The Mission

Mission Statement: “Detect and map the boundaries of geostationary (GEO) communications satellites spot beams by flying a CubeSat(s) through the spot beams at a low earth orbit (LEO) altitude.”

-- Map Spot Beams from GEO
- Frequency targets up to Ka-Band
- Sizes: “Continent” size down to “Island” size

-- CubeSat Bus / Payload
- Small/Simple form factor ==> Easy to integrate
- “Cheap,” possibly even expendable
- 6U version assumed
- Smaller Hardware Emerging
  - RF Payloads
  - “Miniaturized” Bus Subsystems
Possible Option: “Real-Time” C2 Satellite Network (e.g. GlobalStar/Iridium)

Mission profile: Map/Characterize spot beams of target frequency

CubeSat SBM OV-1

Ground Segment

Mission Data and C2: Store and Forward to Ground Station

CubeSat SBM: Record Lat/Lon/Alt/Time info & Track received Power

GEO Comm. Satellites

GEO

LEO
Mission Model: Spot Beams

-- Objective: Simulate collections
-- Model beam patterns of “realistic” spot beams
  - Chose Intelsat Galaxy 28 (G28) as a test case
  - Ku-Band beams -- North and South America (~12 GHz), HPBW
  - C-Band beams ignored (K-Band beams “harder” to find)

Model: North American Region
Intelsat Galaxy 28, Ku-Band Beams

Reference Shape: Satbeams
Intelsat Galaxy 28, Ku-Band Beams

Note: Left is a spherical map projection, right is a Mercator (cylindrical) map projection!
Model: Galaxy 28 Beams

North American & Hawaii Ku-Beam Pattern

*With Perturbations*

South American Ku-beam pattern

Full Version – Shows G-28 Position and South America Beams
Mission Model: Map Concept

Map beams with CubeSats in LEO…
Record space-based position & edges…
Translate to the ground.

3D Beam Pattern – Spot beam mapper in LEO
Simulation: Data Collection Tool

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**MATLAB**
- Creates CubeSat Constellation
- Gives orders to STK
- Calls MSDOS to sort output csv's

**Inputs:**
- Constellation Type
- Orbit Parameters
- Collection Duration
- Payload Sampling

**Systems Tool Kit (STK)**
- Propagates Satellite Orbits
- Generates GPS data within Spot Beams
- Outputs spot beam flythrough info (.csv)

**Contains:**
- GEO Comm-Satellites
- Spot Beam Models
- Access Information

**Spot Beam Map Scenario**

**MSDOS**
- Queue next Access
- "Access = Access + 1"
- Move to desired directory

**Output**
- Full "space" beam map
- Lifetime information
Simulation: Map Generation Tool

Input: Mission “space” data
- Payload collection (GPS)
- Gain information

Outputs:
- Beam edge locations
- “Full” space beam maps
- “Full” ground beam maps

Can observe / analyze:
- Beam Patterns
- Size, position, spread of gaps
- Ground accuracy vs. STK
- Scenario change with time
- Gain patterns within beams
-- Constellation Types
- Single Plane
- Multi-Plane
- Walker Delta
- “Formations”

-- Mission Altitudes
200 to 500 km

-- Mission Inclination
68, 75, 82, 90, 98

-- Payload Data Collection Rate
1, 5, 10 seconds per data point

-- Number of CubeSats per Plane
1-6, 8

-- Number of Orbital Planes
1 – 6 planes

-- CubeSat Spacing / Plane Spacing
Even spacing vs. set sep. angle

-- Collection Duration
1 to 3 days
Simulation: Altitude Considerations

Assumption: Fully loaded 6U CubeSat!

<table>
<thead>
<tr>
<th>Orbit Altitude</th>
<th>Long Case Lifetime (days / years)</th>
<th>Intermediate Case Lifetime (days / years)</th>
<th>Short Case Lifetime (days / years)</th>
<th>Meets Mission Requirements?</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 km</td>
<td>9d / 0.025y</td>
<td>6d / 0.016y</td>
<td>3d / 0.008y</td>
<td>No</td>
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<tr>
<td>300 km</td>
<td>167d / 0.45y</td>
<td>108d / 0.29y</td>
<td>51d / 0.14y</td>
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<tr>
<td>350 km</td>
<td>584d / 1.6y</td>
<td>365d / 1y</td>
<td>177d / .48y</td>
<td>Possible</td>
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<tr>
<td>400 km</td>
<td>2519d / 6.9y</td>
<td>1351d / 3.7y</td>
<td>548d / 1.5y</td>
<td>Yes</td>
</tr>
<tr>
<td>450 km</td>
<td>5402d / 14.8y</td>
<td>4088d / 11.2y</td>
<td>2263d / 6.2y</td>
<td>Yes</td>
</tr>
<tr>
<td>500 km</td>
<td>&gt;9125d / 25y</td>
<td>8870d / 24.3y</td>
<td>4672d / 12.8y</td>
<td>Possible</td>
</tr>
</tbody>
</table>

- 200 km: Too low
- 300 km: Too low
- 350 km: Workable
- 400 km: Good
- 450 km: Good
- 500 km: Workable
Simulation: G-28 NA Beams Sample

Space-based GPS collects mapped to Ground-based points.
68 deg / 350 km / 0.2 Hz / 1 Plane / 6 Satellites / 72 Hour Collection
Simulation: G-28 NA Beams Sample

Space-based GPS collects mapped to Ground-based points.
68 deg / 350 km / 0.2 Hz / 1 Plane / 6 Satellites / 72 Hour Collection
Simulation: Applied in 3-D

In 3D: Galaxy 28 Space-based GPS collects (Red) with ground trace map (Yellow)

In 3D: G-II Space-based GPS collects (Red) with ground trace map (Yellow)
Simulation: Less desirable...

Characteristics of a “Bad” collection:
- Not enough spacecraft
- Not enough collection duration (i.e. time)
- Directly repeating / harmonic ground traces
- Low sampling rate

“Can’t Characterize Beam Shapes”
“Massive Gaps”
“Missing Beams”

Specs:
- 68 deg
- 350 km
- 0.2 Hz
- 1 Plane
- 1 Sat.
- 24 Hour Collection
Simulation: More desirable

Shown: 350km / 68 deg / 6-3-2 Walker Delta / 3 Day Collection
Simulation: Altitude Effects

Goal: Check gap size at mission altitudes

Observations / Main points:

- Altitude selection impacts capability
- Performance can be tailored…
- Some constellations more stable
- More satellites = generally better
- Caveat: Less sats => Need more time
- Repeating ground track… Bad for spot beam mapping
Simulation: Inclination Changes

Spot beam mapping at lower inclinations

- Very good coverage for orbit region
- Shorter collection durations possible
- Cannot find beams at higher latitudes
Simulation: Inclination Changes

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Increasing inclination (up to polar):
- Increases size of latitude gaps
- Can tailor longitude gaps
- Reduces overall “time in beam”

Inclinations for beam mapping:
- Lowest possible inclination
- Covers all desired latitudes
Simulation: Xmitter Position Knowledge

**-- Position knowledge of the GEO transmitters**
- Mandatory to generate accurate ground beam map
- Increased GEO position accuracy = increased ground accuracy

**-- Option 1: (Best) Obtain GEO position information from other sources.**
- Easy; No extra hardware required.
- Ground beam map derived from known transmitter location

**-- Option 2: (Complex) Perform GEO-location on board the CubeSat**
- Difficult; adds *stringent* attitude knowledge requirements
- Extra dedicated hardware likely needed
- Requires more data flow, increases demand for data storage
Simulation: Xmitter Position Knowledge

Option 2: Simulation of on-board GEO-location
i.e. If the CubeSat can draw Lines of Bearing to the Transmitter…
Parameters: 1 Sat / 450km alt / 0.2 hz sensor collect / minor sensor noise / 10m pos. error

- More difficult, complex SDR/antennas likely needed to perform bearing estimate
- Error in estimated position correlates to ground error
- Could fly in clusters to increase accuracy --- adds too much risk & complexity
Attitude Knowledge “noise” reduces GEO-location capability. (i.e. large error)

Ground trace mapping becomes inaccurate when transmitter position knowledge is poorly known.

Kalman-filtering attitude data reduces this error, …even further with SOA CubeSat sensors.
Spot Beam Mapping: On the whole

-- Workable mission for CubeSat Platform
- Simulation tools developed – can generate maps for any constellation
- Best altitudes for established 6U configuration: 350 – 500 km
- Best case: Transmitter position known accurately
- Worst case: Generate angular estimate on board CubeSat

-- Constellation needed for “best” results
- 6+ evenly spaced CubeSats with my assumptions
- 6-3-2 Walker pattern was best from my data sets @ 450km / 68 deg
- Numerous configurations “work” – performance can be tailored.

-- Things to watch out for:
- Directly repeating ground tracks are undesirable
- Accuracy of Ground map at extreme latitudes / longitudes
- Transmitter position knowledge (i.e. the importance of)
Future Work

-- Optimization
- Incorporate tools developed to find best solution
- (Manual approach would take centuries)
- Requires more assumptions with no sponsor (i.e. cost)

-- CubeSat hardware / Subsystem Design & Dev.
- COTS sources vs. new
- Payload selection & supporting hardware
- Form factor trade-offs
- GEO position determination hardware “black-box”

-- Mission Design/Build/Test/Fly
- Would be interesting to compare orbit tests w/findings
- One issue with this “future work” is probably funding
Conclusion

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Questions?
Backup Slides

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- Mission Requirements
- Tracking Received Power
- Vehicle Profile Transition
- More Duration Information
- Results Format
- Simulation 3D
- Transmitter Position Knowledge
- Simulated Payload Sampling Rate
- More ADCS Information
- Geometry
- Ref. Equations
- References / Sources
Bibliography

References / Sources

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