X-band CubeSat Communication System Demonstration

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Outline

• High Level Requirements
• S-, and X-Band CubeSat Communication Subsystems
  – X-band transmitter
  – Antenna Analysis
• End-to-End Comm Analysis
• Development and Measurements
  – Transceiver Test Results
• Communication Demo Using a Balloon
• Conclusion and Future Work
Project

- CU/LASP in collaboration with NASA GSFC, developing a transceiver consisting of X-Band Tx and S-Band Rx under a SmallSat Technology Partnership award (NNX13AR01A), ends 12/2015.
- Develop a radio that is compatible with NEN and can be accommodated by a CubSat
  - 200kbps S-band command uplink
  - 12.5Mbps X-band data downlink
- Approach
  - Use COTS parts
  - Minimize complexity and features
    - Push complexity to software where possible (SDR approach)
  - Use RF software design tools to expedite process
- Schedule
  - Year 1
    - Develop and mature X-band TX from TRL-3 to TRL-5
    - Engage students in the preliminary design of S-band receiver
  - Year 2
    - Develop and mature S-band RX from TRL-3 to TRL-5
High-Level CubeSat Radio Requirements

• CubeSat transceiver designed to be compatible with NASA’s NEN and comply with waveform-specific performance requirements
• Other requirements are:
  – Compatibility with a 6U CubeSat
  – Operation for 12 months in LEO
  – Tx to transmit up to 12.5 Mbps
  – Tx to support OQPSK modulation
  – Tx to support forward error correction coding
  – Tx to have sufficient power to close the link between LEO and NEN
  – Rx capable of closing the link between LEO and NEN, and
  – Operating temperature between -20C and +50C.
S-, and X-Band CubeSat Communication Subsystems

- CU/GSFC developed X-band Transmitter Overview:

<table>
<thead>
<tr>
<th>XTX Capability</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>7800 to 8500 MHz</td>
</tr>
<tr>
<td>Output Power</td>
<td>Up to 0.5W (27dBm)</td>
</tr>
<tr>
<td>Data Interface</td>
<td>LVDS</td>
</tr>
<tr>
<td>Command Interface</td>
<td>RS-422 (can support SPI)</td>
</tr>
<tr>
<td>RF Interface</td>
<td>SMA</td>
</tr>
<tr>
<td>Operating Voltage</td>
<td>8.0V</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK or OQPSK</td>
</tr>
<tr>
<td>Forward Error Correction</td>
<td>Convolutional Encoding</td>
</tr>
</tbody>
</table>

Key Features Include:
- Capable of 50Mbps data rate
- Up to 27dBm RF output
- BPSK and OQPSK modulation
- Highly flexible FPGA based software defined radio
- Compatible with NASA Near Earth Network

XTX is now being sold by Blue Canyon Technologies

29th Annual AIAA/USU Conference on Small Satellites, Logan, UT, USA, August 8-13, 2015
**S-, and X-Band CubeSat Communication Subsystems - Low Gain Patch Antennas**

**Ant Dev Corp:** Low Gain S-band Patch
- 0 dBi +/- 40 deg
- 2210 MHz
- 4X4X0.25 inches

**Ant Dev Corp:** Low Gain X-band Patch
- 0 dBi +/- 60 deg
- 8250 MHz
- 1.85X1.85X0.55 inches
- 50 grams
S-, and X-Band CubeSat Communication Subsystems - Medium Gain X-band Patch Array Antenna

Ant Dev Corp: Medium Gain X-band Patch Array Antenna
- 8080 MHz
- 4 elements
- 2.5X2.75X0.13 inches
- Max 9 dBi gain

X-Band 4-Patch Array Antenna (AntDevCo), fc 8080 MHz, 9 dB gain
X-Band CubeSat Medium Gain X-band Patch Array Antenna - Analysis

WFF Far-Field Compact pattern measurement range

X-Band 4-Patch Array Antenna Gain Plot - Etheta Linear, Theta Cut (0 to 360 deg) at theta phi = 0 degrees.

X-Band 4-Patch Array Antenna Gain Plot - Etheta Linear, Theta Cut (0 to 360 deg) at theta phi = 90 degrees.
Assumptions: S-and X-band Simulations

Communication Simulation Scenarios:
- Modeled CubeSat communication from LEO polar orbit: 705 km/98.2 inclination
- Modeled Balloon Launch up to 540 km slant range, closed the link with at least + 3 dB margin

Ground Stations:
- 11.3-m WGS, ASF 3, MGS 10 m
- NEN Minimum Elevation Angle: 5° S-band and 10° for X-band

X-Band Downlink Parameters:
- Frequency: 8212.5 MHz
- Modulation: QPSK
- CubeSat Transmitter Power: 1.5 Watts
- CubeSat Antenna Gain:
  - 0 dBi for X-band patch,
  - 9 dBi X-band patch array
- Data Format: NRZ-L
- Polarization: RHCP
- Coding: Reed Solomon Encoding
- Target Data rate: 12.5 Mbps

S-Band Downlink Parameters:
- Frequency: 2300 MHz
- Modulation: QPSK
- CubeSat Transmitter Power: 1.5 Watts
- CubeSat Antenna Gain: 0 dBi
- Data Format: NRZ-L
- Polarization: RHCP
- Coding: Reed Solomon Encoding
- Target Data rate: 1 Mbps
### X-band Link Analysis

**To Wallops - 11.3m**

<table>
<thead>
<tr>
<th>Link Name (Mission, RF Link)</th>
<th>X-band Comm Demo Downlink</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transmit Frequency</strong></td>
<td>8115.3 MHz</td>
</tr>
<tr>
<td><strong>Transmitter Power</strong></td>
<td>1.5 watts</td>
</tr>
<tr>
<td><strong>Tx Power - dB</strong></td>
<td>1.76 dBW</td>
</tr>
<tr>
<td><strong>Antenna Diameter</strong></td>
<td>0.01 m</td>
</tr>
<tr>
<td><strong>Antenna Efficiency</strong></td>
<td>55%</td>
</tr>
<tr>
<td><strong>Antenna Gain</strong></td>
<td>0 dBi</td>
</tr>
<tr>
<td><strong>S/C Passive Loss</strong></td>
<td>1.3 dB</td>
</tr>
<tr>
<td><strong>S/C Pointing Loss</strong></td>
<td>0.5 dB</td>
</tr>
<tr>
<td><strong>Transmitter EIRP</strong></td>
<td>-0.04 dBW</td>
</tr>
<tr>
<td><strong>Altitude</strong></td>
<td>705 km</td>
</tr>
<tr>
<td><strong>Min. Elevation Angle</strong></td>
<td>10 deg</td>
</tr>
<tr>
<td><strong>Slant Range</strong></td>
<td>2166.10 km, (Altitude: 705 km)</td>
</tr>
<tr>
<td><strong>Free Space Loss</strong></td>
<td>177.34 dB</td>
</tr>
<tr>
<td><strong>Polarization Loss</strong></td>
<td>0 dB</td>
</tr>
<tr>
<td><strong>Atmospheric Loss</strong></td>
<td>0.34 dB (ITU-R P.676 @ 99% Avail)</td>
</tr>
<tr>
<td><strong>Rain Attenuation</strong></td>
<td>0.09 dB (ITU-R P.618 @ 99.99% Avail)</td>
</tr>
<tr>
<td><strong>Scintillation / Multipath Loss</strong></td>
<td>0 Not Considered</td>
</tr>
<tr>
<td><strong>Cloud Attenuation</strong></td>
<td>0 Not Considered</td>
</tr>
<tr>
<td><strong>Station Clear Sky G/T</strong></td>
<td>34.48 dB/K</td>
</tr>
<tr>
<td><strong>Ground Station G/T</strong></td>
<td>32.48 dB/K</td>
</tr>
<tr>
<td><strong>Bolzmann’s Constant</strong></td>
<td>-228.6 dBW / (Hz*K)</td>
</tr>
<tr>
<td><strong>Received Carrier to Noise Density (C/No)</strong></td>
<td>81.27 dB</td>
</tr>
<tr>
<td><strong>Modulation Loss</strong></td>
<td>0 dB</td>
</tr>
<tr>
<td><strong>Information Rate</strong></td>
<td>12.5 Mbps</td>
</tr>
<tr>
<td><strong>TOD Information Rate</strong></td>
<td>68.87 dB</td>
</tr>
<tr>
<td><strong>Differential Encoding/Decoding Loss</strong></td>
<td>0 dB</td>
</tr>
<tr>
<td><strong>User Constraint Loss</strong></td>
<td>0 dB</td>
</tr>
<tr>
<td><strong>Received Eb/No</strong></td>
<td>12.40 dB</td>
</tr>
<tr>
<td><strong>Implementation Loss</strong></td>
<td>3 dB</td>
</tr>
<tr>
<td><strong>Required Eb/No At Decoder</strong></td>
<td>6.4 dB</td>
</tr>
<tr>
<td><strong>Margin</strong></td>
<td>3 dB</td>
</tr>
</tbody>
</table>

**To McMurdo - 10m**

<table>
<thead>
<tr>
<th>Link Name (Mission, RF Link)</th>
<th>X-band Comm Demo Downlink</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transmit Frequency</strong></td>
<td>8115.3 MHz</td>
</tr>
<tr>
<td><strong>Transmitter Power</strong></td>
<td>1.5 watts</td>
</tr>
<tr>
<td><strong>Tx Power - dB</strong></td>
<td>1.76 dBW</td>
</tr>
<tr>
<td><strong>Antenna Diameter</strong></td>
<td>0.01 m</td>
</tr>
<tr>
<td><strong>Antenna Efficiency</strong></td>
<td>55%</td>
</tr>
<tr>
<td><strong>Antenna Gain</strong></td>
<td>0 dBi</td>
</tr>
<tr>
<td><strong>S/C Passive Loss</strong></td>
<td>1.3 dB</td>
</tr>
<tr>
<td><strong>S/C Pointing Loss</strong></td>
<td>0.5 dB</td>
</tr>
<tr>
<td><strong>Transmitter EIRP</strong></td>
<td>-0.04 dBW</td>
</tr>
<tr>
<td><strong>Altitude</strong></td>
<td>705 km</td>
</tr>
<tr>
<td><strong>Min. Elevation Angle</strong></td>
<td>10 deg</td>
</tr>
<tr>
<td><strong>Slant Range</strong></td>
<td>2166.10 km, (Altitude: 705 km)</td>
</tr>
<tr>
<td><strong>Free Space Loss</strong></td>
<td>177.34 dB</td>
</tr>
<tr>
<td><strong>Polarization Loss</strong></td>
<td>0 dB</td>
</tr>
<tr>
<td><strong>Atmospheric Loss</strong></td>
<td>0.38 dB (ITU-R P.676 @ 99% Avail)</td>
</tr>
<tr>
<td><strong>Rain Attenuation</strong></td>
<td>0.6 dB (ITU-R P.618 @ 99.99% Avail)</td>
</tr>
<tr>
<td><strong>Scintillation / Multipath Loss</strong></td>
<td>0 Not Considered</td>
</tr>
<tr>
<td><strong>Cloud Attenuation</strong></td>
<td>0 Not Considered</td>
</tr>
<tr>
<td><strong>Station Clear Sky G/T</strong></td>
<td>32.48 dB/K</td>
</tr>
<tr>
<td><strong>Ground Station G/T</strong></td>
<td>32.5 dB/K</td>
</tr>
<tr>
<td><strong>Bolzmann’s Constant</strong></td>
<td>-228.6 dBW / (Hz*K)</td>
</tr>
<tr>
<td><strong>Received Carrier to Noise Density (C/No)</strong></td>
<td>76.28 dB</td>
</tr>
<tr>
<td><strong>Modulation Loss</strong></td>
<td>0 dB</td>
</tr>
<tr>
<td><strong>Information Rate</strong></td>
<td>5 Mbps</td>
</tr>
<tr>
<td><strong>TOD Information Rate</strong></td>
<td>63.87 dB</td>
</tr>
<tr>
<td><strong>Differential Encoding/Decoding Loss</strong></td>
<td>0 dB</td>
</tr>
<tr>
<td><strong>User Constraint Loss</strong></td>
<td>0 dB</td>
</tr>
<tr>
<td><strong>Received Eb/No</strong></td>
<td>12.41 dB</td>
</tr>
<tr>
<td><strong>Implementation Loss</strong></td>
<td>3 dB</td>
</tr>
<tr>
<td><strong>Required Eb/No At Decoder</strong></td>
<td>6.4 dB</td>
</tr>
<tr>
<td><strong>Margin</strong></td>
<td>3 dB</td>
</tr>
</tbody>
</table>
C/No, Pass Durations for CubeSat S- and X-band to NEN Stations
S-and X-band Space-to-Ground Communication Analysis

<table>
<thead>
<tr>
<th>Ground Station</th>
<th>Wallops (WGS)</th>
<th>Fairbanks (ASF)</th>
<th>McMurodo (MGS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-band</td>
<td>WGS 11.3M</td>
<td>ASF 11M</td>
<td>MGS (10m)</td>
</tr>
<tr>
<td>X-band</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevation Angle (deg)</td>
<td>5</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Max Data Rate (Mbps) (from 705km Alt.)</td>
<td>4.3</td>
<td>42.3</td>
<td>4</td>
</tr>
<tr>
<td>Contact Time Per Day (hrs)</td>
<td>0.71</td>
<td>0.494</td>
<td>1.674</td>
</tr>
<tr>
<td>Latency (hrs)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>4.556</td>
<td>2.032</td>
<td>1.983</td>
</tr>
<tr>
<td>Maximum</td>
<td>11.843</td>
<td>10.032</td>
<td>8.374</td>
</tr>
</tbody>
</table>

Note: Results in this table were generated using the assumptions for the S- and X-band communications payload systems given in previous slide (9 dBi X-band antenna, 0dBi S-band antenna)
Preparation for Balloon Demo - Simulations

24 hours of balloon simulation from WFF to a slant range of 580km

- From launch, a constant rise rate to a float altitude of 37km
- Assumptions of direct eastward bound drift rate of 5km/hr from Wallops Ground Station (WGS) 11.3m
- Balloon reaches a slant range of 580km from WGS 11.3m, the elevation becomes 1 deg.
- For the X-band link, the 3dB margin threshold on a 12.5Mbps link is only crossed when the elevation angle decreases to about 1 degree
- Thus, the SmallSat/Balloon payload radiated power performance assumed in this analysis will not be an issue for a communications link at 12.5Mbps from a balloon trajectory.
S-Band Receiver Development/Testing

- X-Band transmitter design at TRL5
- S-Band receiver design is based on the Analog Devices AD9364 integrated RF agile transceiver IC.
- The AD9364 baseband and down-shifted subcarrier will be fed to an FPGA.

Block diagram of AD9364 and FPGA based digital Costas Loop for BPSK reception

Simulink diagram of Costas loop implemented for verification of performance
Transmitted (blue) and received (green) data from the Simulink model shown in previous slide.

Transmitter BER Test Setup

Receiver I and Q FPGA outputs
Summary

- Analysis of NEN compatible CubeSat S- and X-band communication system:
  - Analyzed different S- and X-band antenna systems, before selecting to optimize communication system performance.
  - Analyzed transmitter performance.
  - Analyzed dynamic comm link for higher science data throughput.
  - Characterized end-to-end system performance as we are preparing for CubeSat communication system demo.
Future Work

- Perform end-to-end X-band CubeSat communication system demo between a balloon and/or sounding rocket and a NEN system.
  - Coordinating with Wallops for launch opportunity

- Develop LASP/GSFC Radio compatible with NEN and SN
  - S- and X-band portion can be modified to be compatible with SN

- Radiation requirements- 100 krads

- Environmental Tests
References


- The Future of CubeSats: http://www.nasa.gov/content/goddard/the-future-of-cubesats/

- NASA Team Set to Deliver Newfangled 6U CubeSat: https://www.nasa.gov/content/goddard/nasa-team-set-to-deliver-newfangled-6u-cubesat


Acknowledgements

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Questions

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