Phase 4B / GEO EMCOMM Preliminary Design Review

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6/17/2016
Joint Cubesat Projects w/ Space@VT

All Cubesats selected for NASA ELaNa launch

1. Lower Atmosphere/Ionosphere Coupling Experiment (LAICE)
   - Developing sensors which hope to reveal new information about the neutral ion coupling processes in the 150 to 325 kilometer atmospheric region. (VT PI: Dr. Greg Earle)
   - Launch: Late 2016, Planned

2. AMSAT FOX-1A (AO-85)
   - Primarily FM Voice Transponder for Amateur Radio. VT developed a 640x480 pixel jpeg camera payload for delivering images of earth from orbit over the high speed downlink. (VT PI: Dr. Robert McGwier)
   - Launch: 8 Oct. 2015 (ELaNa XII on NROL-55)

3. DUST Sounder and Temperature Imager Experiment (DUSTIE)
   - Determine the global distribution of cosmic "smoke" in the atmosphere. (VT PI: Dr. Scott Bailey)
   - Launch: TBD

4. QB50
   - The Virginia Tech Ground Station supports the QB50 project by providing ground station services.
Thank you for your support!

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GEO EMCOMM Payload Preliminary Design Review

Dr. Jonathan Black
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Outline

• Introductions, Mission Overview & Motivation
• Mechanical Design
• Thermal Design
• Power Supply Design
• RF Design
• AstroSDR Review
• Reset Receiver Design
• Communications Software Architecture
• Antenna Design & Link Budget Analysis
Mission Overview

Hands on, Minds on; RF and Security Research at Virginia Tech:
- On-orbit learning laboratory to develop new capabilities in satellite communications and amateur radio
- Digital protocols to enable push-to-talk, wifi, streaming video, etc.
- Onboard processing - geolocation, co-channel, machine learning
- App development and real time experimentation
- Beam steering and coordinated collection
- User authentication and prioritization
- Open cryptography

Program Reach:
- Free and open access to the repeater to amateur radio operators worldwide.
- Deployable Ground Stations to provide coverage (wifi hotspots and push-to-talk) through the GEO asset
- Students from across Virginia Tech engaged in payload design and development, and amateur radio operations through the Virginia Tech Ground Station
Mission Overview and Requirements

- AMSAT Phase4B Project Program Specifications:
  - SDR-based 5 & 10 GHz amateur satellite payload being designed to take advantage of a geosynchronous launch opportunity
  - Rideshare opportunity on REDACTED
  - Software-defined radio (SDR) payload from Rincon Research Corporation

- Program Partners:
  - FEMA
  - AMSAT
  - ARRL
  - Rincon Research Corporation
  - REDACTED
  - Virginia Tech
    - Hume Center
    - Space@VT
    - Electrical and Computer Engineering
    - Mechanical Engineering
    - Aerospace and Ocean Engineering
Publicity

- FEMA Blog
  - https://www.fema.gov/blog/2016-03-07/supporting-disaster-communications-space

- VT News
  - http://www.vtnews.vt.edu/articles/2015/12/122215-ictas-humegeoradio.html

- ARRL
  - http://www.arrl.org/amateur-radio-emergency-communication
Preliminary Schedule

- **Spring Semester 2016**
  - Project Kickoff – 15 Jan 2016
  - Preliminary Interface Control Document delivered (MSS to AMSAT/VT) – 19 Feb 2016
  - Payload PDR – 27 May 2016
  - Payload Accommodation PDR – TBD

- **Summer 2016**
  - Payload CDR – 5 Aug 2016

- **Fall 2016**
  - EM Payload Testing complete – 16 Sept 2016
  - Payload Test Readiness Review – 4 Nov 2016
  - Payload Integration Readiness Review – 20 Dec 2016
  - Payload Delivery and Integration start – 2 Jan 2017
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**Mass Budget**

- **High level overview**
  - Nadir Deck Enclosure—communication processing
  - Internal Enclosure—Power conditioning and distribution

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass [kg]</th>
<th>Source</th>
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<tbody>
<tr>
<td>Nadir Deck Enclosure</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>Antennas - Uplink/Downlink</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Antenna - Reset Receiver</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Internal Enclosure (including estimated payload)</td>
<td>7.724</td>
<td></td>
</tr>
<tr>
<td>Wiring</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Screws/harnessing</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Low Noise Amplifiers</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Combiner</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Frequency reference</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>AstroSDR</td>
<td>0.3</td>
<td>Rincon—March 11, 2016</td>
</tr>
<tr>
<td>Heat Plate/RF Shield</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Local Oscillator</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Mixer</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Filter</td>
<td>0.1</td>
<td></td>
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<tr>
<td>Phase shifter</td>
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<td>Splitter</td>
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<td>Transmit Driver Amp</td>
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<td>Power Amplifiers</td>
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<tr>
<td>Power conditioning</td>
<td>0.5</td>
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</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>16.124</strong></td>
<td></td>
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</table>
Internal Enclosure Preliminary Design

<table>
<thead>
<tr>
<th>Part</th>
<th>Material</th>
<th>Mass</th>
</tr>
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<tbody>
<tr>
<td>Lower Housing*</td>
<td>Al 6061</td>
<td>3.667 kg</td>
</tr>
<tr>
<td>Upper Housing*</td>
<td>Al 6061</td>
<td>3.307 kg</td>
</tr>
<tr>
<td>PC104 Card Cage</td>
<td>Aluminum, Steel, Silicone</td>
<td>approx. 0.75 kg</td>
</tr>
<tr>
<td>*Fabricated at the Virginia Tech AOE Machine Shop</td>
<td>Total:</td>
<td>7.724 kg</td>
</tr>
</tbody>
</table>

6/17/2016 GEO EMCOMM Payload PDR
Internal Enclosure (payload)

- PC/104 Card Cage (Curtiss-Wright)
  - COTS component
  - 4”, 6”, 8”, and 10” rail options
  - shock absorbers effectively reduce G-loads in 3 dimensions by up to a factor of 10
  - PC/104 PCB standards (approx. 90 x 96 mm)

<table>
<thead>
<tr>
<th>P/N</th>
<th>Description</th>
<th>Lead Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRV-1205-01</td>
<td>Non-Slotted Aluminum Rail Set, 4&quot; Length, Holds up to 5 Cards</td>
<td>Ship 8-10 Weeks ARO</td>
</tr>
<tr>
<td>PRV-1206-01</td>
<td>Non-Slotted Aluminum Rail Set, 6&quot; Length, Holds up to 8 Cards</td>
<td>Ship 8-10 Weeks ARO</td>
</tr>
<tr>
<td>PRV-1207-01</td>
<td>Non-Slotted Aluminum Rail Set, 8&quot; Length, Holds up to 11 Cards</td>
<td>Ship 8-10 Weeks ARO</td>
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<tr>
<td>PRV-1208-01</td>
<td>Non-Slotted Aluminum Rail Set, 10” Length, Holds up to 14 Cards</td>
<td>Ship 8-10 Weeks ARO</td>
</tr>
<tr>
<td>PRV-0439-03</td>
<td>CARD CAGE ENDCAP, 4&quot; X 4&quot;, W/3&quot; SQUARE CUTOUT</td>
<td>Ship 8-10 Weeks ARO</td>
</tr>
</tbody>
</table>
Nadir Deck Enclosure

- Designed similar to the Internal Enclosure with additional room next to the PC/104 Card Stack to accommodate antenna

Antenna mounting area

Area for antenna internals

Payload mounting area

REDACTED

REDACTED

IMAGE REDACTED
Nadir Deck Enclosure (AstroSDR)

- AstroSDR design conforms to the CubeSat Next Generation Bus (CNGB) specification
  - Contacted the distributors of the CNGB frame structure– direct purchase from vendor is not available at this time...
- Heat Plate
  - Designed to conform to PC/104 dimensions
  - Mounts directly to AstroSDR
  - Will securely mount to PC/104 Card Cage rails
  - Manufactured in-house (Virginia Tech AOE Machine Shop)
Preliminary Analysis (Internal Enclosure)

- Pressure Decay/Venting
  - The Payload Provider shall design components to withstand a maximum pressure decay rate of inside of the Payload fairing. Transonic spike(s) up to shall be acceptable.

- Preliminary Vent Design
  - NASA JPL established an empirical rule for venting adequacy
    - If $V/A < 2000$ inches, then no further venting analysis needed
    - Internal volume, $V \approx 208$ in$^3$
    - Venting area, $A = 0.346$ in$^2$ (10X Ø .210 inch venting holes)
    - Resulting $V/A = 600.53$ in

- Maximum 7.75e-3 mm deformation, 4.5 Mpa stress
Preliminary Analysis (Internal Enclosure)

- Modal Analysis
  - The fundamental mechanical mode of the Internal Enclosure shall be greater than REDACTED
    - 1st mode occurs at approximately 3000 Hz
  - The fundamental mechanical mode of the Nadir Deck Enclosure shall be greater than REDACTED
Preliminary Analysis (Internal Enclosure)

• Random Vibration
  • The payload provider will test to the random vibration environment specified for a duration of REDACTED or longer per each of three orthogonal axes

• Maximum deformation and stress occur from x-axis loading
  • 1.50e-3 mm deformation
  • 0.77 Mpa stress
Preliminary Analysis (Internal Enclosure)

- **Shock**
  - The internally mounted payload will be qualification tested in accordance with the shock spectrum shown. The spectrum shape will be controlled to within and will be applied in each of three orthogonal axes. At least spectrum amplitudes will exceed the nominal test specification.

- **Maximum deformation and stress** occur from z-axis loading
  - 0.052 mm deformation
  - 27.3 Mpa stress
Preliminary Mechanical Schedule

• Summer 2016
  • Order PC/104 Card cages and obtain NDA for proprietary CAD models of PC/104 Card cage – 1 June 2016
  • Finalized designs of both Nadir Deck and Internal Enclosures – 15 June 2016
  • Order aluminum blanks from McMaster-Carr – 16 June 2016
  • Engineering models sent in to machine shop – 24 June 2016
  • Receive engineering models from machine shop – 22 July 2016
  • Integrate engineering models for testing and evaluation – 27 July 2016
  • Integrated engineering model tested in the VAST lab – 1 August 2016
  • Post-process test data and compare/re-evaluate simulations – 4 August 2016

• Fall 2016
  • Prepare to send detailed design unit to machine shop – 1 September 2016
  • Integration – 1 November 2016
  • Final Vibration and TVAC testing in the VAST Lab – 12 November 2016
  • Receive validated final design from testing and evaluation – 12 December 2016
  • Prepare for delivery – 19 Dec 2016
Testing

• Thermal/Vacuum: VAST lab, Langley, Wallops, Morehead St...

• Shake/vibration: Vibrations, Adaptive Structures and Testing (VAST) Laboratory at Virginia Tech
  • Zonic WCA Signal Analyzer: especially useful for experimental dynamic and acoustic structural analysis (also have SigLab and several other PC-based analyzers)
  • Newport vibration isolation table
  • Polytec PI Laser-Doppler Vibrometer and Scanner: allows mapping of modal data on surfaces of large structures. (e.g., PSV-400 with a 1 MHz range and close up modules, OFV-500 and PDV-100 portable units)
  • A 64-cubic feet environmental chamber is also available, allowing temperature and pressure controlled experiments
Outline

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- Mechanical Design
- **Thermal Design**
- Power Supply Design
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- Antenna Design & Link Budget Analysis
Thermal Analysis of External Environment

• Simulation Plan
  • Perform 2 radiation thermal analysis’ on external CAD drawing using SINDA and Thermica.
  • Perform 2 conduction thermal analysis’ on internal CAD drawing using SINDA and Thermica for the worst case conditions.
  • For the “Hot case”  \( T = 80^\circ C \)
  • For the “Cold case”  \( T = -80^\circ C \)
Thermal Analysis of Internal Environment

- **Analysis Assumptions**
  - Dimensions based on "internal_rev2" drawing
  - Box is coated with Z307 black paint ($e = 0.89$)
  - Thermally isolated from payload

- **Predictions**
  - Box temperature range: $45^\circ C$ to $-38^\circ C$

Heat load = 20W on baseplate
This is just an estimate.
Sil-Pad between box and nadir deck. $0.733 \leq \frac{W}{^\circ C \text{ in}^2} \leq 1.315$
Thermal Analysis of Internal Environment

• Simulation Plan
  • Radiation flux produced by internal components is small compared to those produced by the Sun and Earth, therefore a radiation analysis is not necessary.
  • Perform 2 conduction thermal analysis’ on internal CAD drawing using SINDA and Thermica for the worst case conditions.
  • For the “Hot case”: 45°C
  • For the “Cold case”: -38°C
Thermal tolerance during launch

- Internal box temperature range of -38°C to 45°C.
- In order to keep SDR warm, implement heaters.
- Minco Polyimide Thermofoil Heaters can operate at a temperature range of -200°C to 200°C.

<table>
<thead>
<tr>
<th>Size (inches)</th>
<th>Size (mm)</th>
<th>Type</th>
<th>Resistance in ohms*</th>
<th>Typical power</th>
<th>Effective area in² (cm²)</th>
<th>Lead AWG</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>Y</td>
<td>X Y</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.50</td>
<td>2.00</td>
<td>12.7</td>
<td>50.8</td>
<td>157</td>
<td>0.79 (5.10)</td>
<td>30</td>
</tr>
<tr>
<td>0.50</td>
<td>4.00</td>
<td>12.7</td>
<td>101.6</td>
<td>78.4</td>
<td>1.67 (10.77)</td>
<td>30</td>
</tr>
<tr>
<td>0.50</td>
<td>6.00</td>
<td>12.7</td>
<td>152.4</td>
<td>52.3</td>
<td>2.35 (15.16)</td>
<td>30</td>
</tr>
</tbody>
</table>

Watt Density for T = -38°C
Mounting Method:
- Acrylic PSA = 20 W/in²
- Epoxy = 47 W/in²
- Stretch Tape or Clamped = 50 W/in²
Preliminary Thermal Schedule

• Summer 2016
  • Complete initial SINDA tutorials and workshops – 29th July 2016
  • Complete thermal model of internal environment and recommend heater specs. – 28th August 2016

• Fall 2016
  • Complete thermal model of external environment – 28th October 2016
  • Have all thermal models completed with all final components incorporated – 1 Nov 2016
  • Software Load – 1 Dec 2016
  • Complete all thermal testing – 16th Dec 2016
  • Finish a short report/summary on thermal environment and solutions – 31 Dec 2016
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Power Distribution Layout

Diagram does not suggest or imply final connections of devices!
Power Conditioning

Currently at 4 DC-DC Converters and a EMI Filter from VPT.

- Close proximity (at the CRC)
- Already tested to be space-rated and rad-hard/tolerant
- Can be used in conjunction with capacitors and diodes to deal with transients and in-rush currents
- Possible limitations due to size and weight?

- Power efficiency expected between 80 to 86%
  - EMI Filter power lost is 9W

- Possible low lead times
## Power Budget

<table>
<thead>
<tr>
<th>Item</th>
<th>Max Expected Power Drain</th>
<th>Average Voltage</th>
<th>Average Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>AstroSDR</td>
<td>20 W (typical drain of 12W-18W)</td>
<td>12 V dc (7V-13.2V dc raw input)</td>
<td>1.7 A</td>
</tr>
<tr>
<td>Power Amplifier (for each of 4 antennas)</td>
<td>80 W (total)</td>
<td>20 V dc (per antenna)</td>
<td>1 A (per antenna)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item Still Under Review</th>
<th>Estimated Power Drain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcontroller</td>
<td>0.25 W</td>
</tr>
<tr>
<td>Low Noise Amplifiers</td>
<td>5 W</td>
</tr>
<tr>
<td>10 MHz Reference</td>
<td>5 W</td>
</tr>
<tr>
<td>Local Oscillator</td>
<td>5 W</td>
</tr>
<tr>
<td>Phase Shifter</td>
<td>2 W</td>
</tr>
<tr>
<td>Transmit Driver Amp</td>
<td>3 W</td>
</tr>
<tr>
<td>Reset Receiver</td>
<td>0.5 W</td>
</tr>
<tr>
<td>Sensors</td>
<td>1 W</td>
</tr>
<tr>
<td>EMI Filter</td>
<td>9 W</td>
</tr>
</tbody>
</table>

- Many components or devices have not been finalized.
  - High-end estimations based on previous experiences
- Estimated power drain, after efficiency lost at full load, is 130.75 W.
Power Budget

- First look at power conservation involved the idea to “turn on” and “turn off” the payload’s components as needed
  - Required a lot of overhead
  - Greatly limits active operational time
  - Was limited by what we didn’t know at the time (component power cost)

- Reviewed the issue after getting a better idea of possible power efficiency numbers
  - By keeping efficiency >80%, we can stay on at all times at 80W (the equivalent of disabling two power amplifiers)
  - Can temporarily enable the other two amplifiers with the proper amount of overhead beforehand
  - Requires further review
Electrical Interfaces

- Payload/host interconnect: wire, connectors to interface with Millennium host are TBD from Millennium
- Payload-subsystem interconnects: VT will determine and be responsible for these. Still TBD based on power requirements
Preliminary Power Schedule

• Summer 2016
  • Finalize resettable fuse design – 1 July 2016
  • Finalize EMI filtering – 10 July 2016
  • Preliminary DC-DC conversion design – 5 August 2016
  • Preliminary host interconnects – 5 August 2016
  • Preliminary wiring harnesses & distribution – 5 Aug 2016

• Fall 2016
  • Finalize DC-DC conversion design – 20 September 2016
  • Finalize host interconnects – 1 October 2016
  • Finalize wiring harnesses & distribution – 15 October 2016
  • Integrate into payload – 1 November 2016
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Transmitter Starting Point

- 0 dBm
- 1 mW
- -30 dBW

0 dBm
1 mW
-30 dBW

f_{IF} = ? MHz

13 dBm
20 mW
-17 dBW

13 dBm
20 mW
-17 dBW

HPA

40 dBm
10 W
10 dBW

40 dBm
10 W
10 dBW

fc = 10.475 GHz

fc = 10.475 GHz
Potential Transmitter Architecture

0 dBm
1 mW
-30 dBW

Loss = 7 dB

$\text{f}_\text{RF} = 475 \text{ MHz}$

Mixer

Loss = 3 dB

$\text{f}_\text{c} = 10.475 \text{ GHz}$

VCO

Loss = 1 - 3 dB

4-Way Splitter

Pre Amp

Gain = 26 dB

Pre Amp

Gain = 27 dB

Pre Amp

Pre Amp

HPA

HPA

HPA

HPA

40 dBm
10 W
10 dBW

6/17/2016

GEO EMCOMM Payload PDR
### Potential Mixers

<table>
<thead>
<tr>
<th>Device</th>
<th>Analog Devices HMC-C049</th>
<th>Marki Microwave IRW-0618</th>
<th>Analog Devices HMC1056LP4BE</th>
<th>Analog Devices HMC9059</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Passive Double Balanced GaAs MMIC</td>
<td>Passive Image Reject</td>
<td>Passive Image Reject GaAs MMIC</td>
<td>Active Image Reject GaAs MMIC</td>
</tr>
<tr>
<td>RF Frequency (GHz)</td>
<td>7.0 – 11.0</td>
<td>6.0 – 18.0</td>
<td>8.0 – 12.0</td>
<td>9.5 – 13.5</td>
</tr>
<tr>
<td>LO Frequency (GHz)</td>
<td>7.0 – 11.0</td>
<td>6.0 – 18.0</td>
<td>8.0 – 12.0</td>
<td>6.0 – 17.0</td>
</tr>
<tr>
<td>IF Frequency (GHz)</td>
<td>DC – 5.0</td>
<td>DC – 0.210</td>
<td>DC – 4.0</td>
<td>2.0 – 8.0</td>
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<tr>
<td>LO to RF Isolation (dB)</td>
<td>48</td>
<td>35</td>
<td>40</td>
<td>10</td>
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<tr>
<td>LO to IF Isolation (dB)</td>
<td>35</td>
<td>25</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>RF to IF Isolation (dB)</td>
<td>22</td>
<td>25</td>
<td>Not Rated</td>
<td>Not Rated</td>
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<tr>
<td>Conversion (dB)</td>
<td>-7</td>
<td>-7.5</td>
<td>-8</td>
<td>+15</td>
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<tr>
<td>Loss(-)/Gain(+)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sideband Rejection (dBc)</td>
<td>Not Rated</td>
<td>23</td>
<td>25</td>
<td>22</td>
</tr>
</tbody>
</table>
## Double Balanced vs. Image Reject

<table>
<thead>
<tr>
<th>Device</th>
<th>Analog Devices</th>
<th>Marki Microwave</th>
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<tbody>
<tr>
<td></td>
<td>HMC-C049</td>
<td>IRW-0618</td>
</tr>
<tr>
<td><strong>Type</strong></td>
<td>Passive Double Balanced</td>
<td>Passive Image Reject</td>
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<tr>
<td><strong>IF Frequency (GHz)</strong></td>
<td>.475</td>
<td>.175</td>
</tr>
<tr>
<td><strong>LO Frequency (GHz) [Low Side Injection]</strong></td>
<td>10</td>
<td>10.3</td>
</tr>
<tr>
<td><strong>RF Frequency (GHz) [LO+IF]</strong></td>
<td>10.475</td>
<td>10.475</td>
</tr>
<tr>
<td><strong>Image Frequency (GHz) [LO-IF]</strong></td>
<td>9.525</td>
<td>10.125</td>
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<td><strong>Image Filter</strong></td>
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<tr>
<td><strong>LO to RF Isolation (dB)</strong></td>
<td>48</td>
<td>35</td>
</tr>
<tr>
<td><strong>LO to IF Isolation (dB)</strong></td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td><strong>RF to IF Isolation (dB)</strong></td>
<td>22</td>
<td>25</td>
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<tr>
<td><strong>Conversion (dB)</strong></td>
<td>-7</td>
<td>-7.5</td>
</tr>
<tr>
<td><strong>Loss(-)/Gain(+)</strong></td>
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<td></td>
</tr>
<tr>
<td><strong>Sideband Rejection (dBc)</strong></td>
<td>Not Rated</td>
<td>23</td>
</tr>
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</table>
Voltage Controlled Oscillator

- Device: TGV2563-SM
- Frequency Range: 9.7 – 10.8 GHz
- Tune Voltage: 2 – 13 V
- Output Power: 11 dBm
- Bias: Vcc = 5 V, Icc = 175 mA
- Power Dissipation = 0.875 W
- Storage Temperature = -65°C – 125°C
- Tested Operating Temperature = -40°C – 85°C
- May need Phase Locked Loop Circuit
## Potential Pre-Amplifiers

<table>
<thead>
<tr>
<th>Device</th>
<th>Analog Devices HMC608LC4</th>
<th>Qorvo (TriQuint) TGA2501-GSG</th>
<th>Qorvo (TriQuint) TGA2625</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (GHz)</td>
<td>9.5 – 11.5</td>
<td>6.0 – 18.0</td>
<td>10.0 – 11.0</td>
</tr>
<tr>
<td>Gain (dB)</td>
<td>29.5</td>
<td>26</td>
<td>37</td>
</tr>
<tr>
<td>Vd (V)</td>
<td>5</td>
<td>8</td>
<td>28</td>
</tr>
<tr>
<td>Output IP3 (dBm)</td>
<td>33</td>
<td>Not Rated</td>
<td>Not Rated</td>
</tr>
<tr>
<td>Output P1dB (dBm)</td>
<td>27, Pin = -4 dBm</td>
<td>34*, Pin = 10 dBm</td>
<td>~ 42, Pin = 7 dBm</td>
</tr>
<tr>
<td>Output Power (dBm)</td>
<td>20, Pin = -10 dBm</td>
<td>16*, Pin = -10 dBm</td>
<td>27*, Pin = -10 dBm</td>
</tr>
<tr>
<td>PAE (%)</td>
<td>~ 7.5, Pin = -10 dBm</td>
<td>32, Pin = 15 dBm</td>
<td>&gt; 15*, Pin = -10 dBm</td>
</tr>
<tr>
<td>Power Dissipation (W)</td>
<td>~ 1.55</td>
<td>~ 9.6</td>
<td>~ 10.22</td>
</tr>
</tbody>
</table>

* Extrapolated Qualitative Estimation from Data Sheet
High Power Amplifier

- Device: Qorvo TGA2625-CP
- Frequency: 10 GHz
- Gain: 27 dB at 1-dB compression
- PAE: 45-50%
- Drain Voltage: 20V
- Power Dissipation = 20 W
- $P_{out}: 10W$ (46 dBm) @ $P_{in} = -13$ dBm, Saturation
- Storage Temperature = -55°C – 150°C
- Tested Operating Temperature = -40°C – 85°C
Potential Receiver Architecture

- **Temperature (T)**: 273 K
- **Bandwidth (BW)**: 10 MHz
- **Noise Figure (NF)**: -104 dBm

**Block Diagram**:
- **4-Way Combiner**
  - Loss = 3 dB
  - NF = 3 dB
- **Filter**
  - Loss = 3 dB
  - NF = 3 dB
- **LNA**
  - Gain = ?
  - NF = 1 - 2 dB
- **2-Way Combiner**
  - Loss = 3 dB
  - NF = 3 dB
- **Astro SDR**

**Frequencies**:
- **fc**
- **fc**
- **fc**
- **fc**

**Center Frequency (fc)**: 5.66 GHz
## Potential LNAs

<table>
<thead>
<tr>
<th>Device</th>
<th>Qorvo (TriQuint) TQ8M9037</th>
<th>Qorvo (TriQuint) TGM2543-SM</th>
<th>Qorvo (TriQuint) TGA2512-SM</th>
<th>API Tech Corp (Spectrum Microwave) BXHF1070</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency (GHz)</strong></td>
<td>0.7 – 6.0</td>
<td>4.0 – 20.0</td>
<td>4.0 – 14.2</td>
<td>5.0 – 10.0</td>
</tr>
<tr>
<td><strong>Gain (dB)</strong></td>
<td>11</td>
<td>17</td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td><strong>Noise Figure (dB)</strong></td>
<td>1.2</td>
<td>1.7</td>
<td>2.5</td>
<td>3.8</td>
</tr>
<tr>
<td><strong>Output IP3 (dBm)</strong></td>
<td>31</td>
<td>30</td>
<td>21</td>
<td>41</td>
</tr>
<tr>
<td><strong>Output P1dB (dBm)</strong></td>
<td>22</td>
<td>18</td>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td><strong>Vd (V)</strong></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td><strong>Power Dissipation (W)</strong></td>
<td>0.35</td>
<td>0.5</td>
<td>0.8</td>
<td>5.28</td>
</tr>
<tr>
<td><strong>Additional Capability</strong></td>
<td>AGC</td>
<td>AGC &amp; Limiter</td>
<td>AGC</td>
<td></td>
</tr>
</tbody>
</table>
Preliminary RF Schedule

• Summer 2016
  • Mixer Analysis and Design – 8 June 2016
  • Image Filter Design & 4-Way Splitter Selection – 15 June 2016
  • Voltage Controlled Oscillator Analysis and Design – 22 June 2016
  • Pre-Amplifier Analysis and Design – 29 June 2016
  • LNA Design – 6 July 2016
  • LNA Filter Design – 13 July 2016
  • Order Parts and Get Price Quotes – 31 August 2016

• Fall 2016
  • Test individual RF components – 7 September 2016
  • Build RF transmit chain prototype – 5 October 2016
  • Test RF transmit chain prototype – 26 October 2016
  • Build RF receive chain prototype – 9 November 2016
  • Test RF receive chain prototype – 30 November 2016
  • RF Design Integration with Payload – 31 December 2016
Outline

- Introductions, Mission Overview & Motivation
- Mechanical Design
- Thermal Design
- Power Supply Design
- RF Design
- AstroSDR Review
- Reset Receiver Design
- Communications Software Architecture
- Antenna Design & Link Budget Analysis
AstroSDR – Hardware

• Receiving “serial -015”
• Xilinx Zynq 7045 All-Programmable SOC
• AD9361(Catalina) - 2x2 RF Agile Transceiver
• High reliability boot and OS storage
• High reliability power supplies
• Further slides redacted due to propriety information to Rincon Research
Outline

• Introductions, Mission Overview & Motivation
• Mechanical Design
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Reset receiver design slides redacted due to proprietary information of AMSAT - North America.
Outline

- Introductions, Mission Overview & Motivation
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Communications Architecture

- FDMA
- TDM

Disaster Area

Disaster Coordinators
Minimum Uplink Design

10 MHz Uplink → 100 – 100 kHz Channels → { 90 User Channels, 3 Control Channels, 7 Random Access Channels }

95 kHz Available

100 kHz Control Channel
100 kHz Random Access Channel
100 kHz User Channel
100 kHz User Channel
100 kHz User Channel
100 kHz User Channel
100 kHz User Channel
Assuming 95 kHz Available for Users

\[ R_b = \frac{r \times 95 \text{ kHz}}{\log_2(M) \times (1 + \alpha)} \]

- M is the modulation order
- \( \alpha \) is the rolloff factor of RRC Filter
- r is the total code rate used
- \( R_b \) is the bit rate

Example:
QPSK 13/45 (\( r = \frac{93}{95} \times 13/45 \)) with \( \alpha = 0.33 \)

\[ R_b = 10.2 \text{ kbps} \]
Communications Architecture

EMCOMM Transponder

AstroSDR

N Channel Channelizer

Detect

Demod

Repackaging into TDM Structure

Reset Receiver

10 GHz Downlink
Software Test Plan

• There will need to be verifications during (if allowed) and after each test.
• There will need to be software and hardware checks that are done in software to ensure we maintain functionality of all parts during test
• We may not be able to transmit during these tests, so we will need to have checks that can be run without this
  • This could also be used if the transponder is in transfer orbit
Preliminary SF Schedule

• Summer 2016
  • Initial GNURadio Demo – 3 June 2016
  • Initial Uplink/Downlink Design – 1 July 2016
  • Complete GNURadio Demo – 15 Aug 2016

• Fall 2016
  • Payload Test Software – 1 Sept 2016
  • RFNoC Implementation – 1 Nov 2016
  • Software Load – 1 Dec 2016
  • Software Test Finished – 31 Dec 2016
Outline

- Introductions, Mission Overview & Motivation
- Mechanical Design
- Thermal Design
- Power Supply Design
- RF Design
- AstroSDR Review
- Reset Receiver Design
- Communications Software Architecture
- Antenna Design & Link Budget Analysis
Link Budgets – Original Design Goals/Givens

- Geosynchronous Orbit @ Orbital Slot (REDACTED assume 4 deg inclination)
- CONUS Coverage
- 40W TX Power
- Linear Polarization
- 10 MHz Noise Bandwidth
  - Since Downlink is single TDMA Stream, Ground Stations will have to receive the ENTIRE Aggregate 10 MHz.
- 0.6m G/S Diameter Reflector Antenna
- No or minimal Tracking required on the ground.
- Beam steering on S/C is desirable.
  - Downlink only for Security reasons.
- DVB-S2 and DVB-S2X Protocol
Antenna Design – Commercial

- Surveyed commercial available antennas
- Corrugated conical horn (A-Info)
  - Frequency: 8.2 – 12.4 GHz
  - Gain: 20.5 dB
  - 3 dB BW: 16° to 16.5°
  - Mass: ≈1.7 kg
Antenna Design – Dual-band horn

- Option to combine uplink/downlink into one antenna
- Gain: 19.6 dBi

This face can be used to dissipate heat into the main spacecraft

Dual mode 10 GHz waveguide (TE_{11} and TM_{11})
Single mode 5 GHz waveguide (TE_{11})

Conical horn to increase aperture

Aperture 8240 mm²
(102.4 mm diam)
Antenna Design – Dual-band horn array

• To do beam steering, make an array of 4 horns
• Gain: 24.2 dBi

[Diagram of antenna array]

[Graph showing radiation pattern]
Antenna Design – Conical horn

- For use on the downlink
- Challenge is wide-enough main beam with quick rolloff
- Gain: 20.1 dBi
- 3 dB BW: 18°
Link Budgets – Other Assumptions

Assumptions

• Center Frequency: 10.475 GHz
• Target BER 10e-5 or better
• 1.0 dB implementation Loss
• RX System Noise Figure: 1.3 dB (<1.0dB NF LNA/LNB mounted close to feed)
• RX System Antenna Efficiency: 55%
• Phase Shift Keying modulations (BPSK/QPSK/8PSK) from DVB-S2(X) standards. (No QAMs due to saturated transponder PAs)
• -3.0 dB contour Loss
• NO polarization Loss (assume the operator has aligned the feeds)
• No Rain Fade analysis considered yet
• Minimal atmospheric losses
QUESTIONS?