An Observation of VLF EM Waves Emitted by Lightning

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Schmitt, Jacob Allard, Breonna McMahon, Brant Carlson

February 13, 2017
Presentation Outline

• Section 1: Mission Overview
• Section 2: Final Design Description
• Section 3: Project Management Update
• Section 4: Hardware Procurement Status
• Section 5: Subsystem Testing Results
• Section 6: Integrated Subsystem Testing Plan
• Section 7: User Guide Compliance
Mission Statement

The objective of our research project is to observe very low frequency (VLF) electromagnetic (EM) waves emitted from natural lightning discharges as a function of altitude.

Figure 1: Spectrogram of recorded VLF EM wave data from the University of Greece
Radio atmospheric signals are broadband electromagnetic impulses generated by natural lightning discharges.

VLF EM wave signals range in frequency from 3-30 kHz.

With such big wavelengths, signal can be picked up anywhere around the world.

VLF EM waves interact with Ionosphere.

Image courtesy of Stanford VLF Group.
Electromagnetic waves such as sferics reflect from the ionosphere

Some energy escapes into magnetosphere

This energy may play a role in the removal of energetic particles from the radiation belts

Importance: These particles can degrade and destroy satellites especially in periods of strong solar activity

This reflection process has not been observed in situ
Past Experimentation

- Experiment flown on sub-orbital rocket through RockSat-X program in August 2016
- Experiment was unfortunately deemed unrecoverable by NASA
- Sampling frequency of Wallops Flight Facility (WFF) transmitted telemetry data was too slow (~1.5 kHz) to observe VLF EM wave signal due to Nyquist Theorem
- With 60 Hz being one of the most common frequencies that power lines emit, it was a very dominant signal within our spectrograms seen in Figure 1 and Figure 2

Figure 1: FFT of Analog Telemetry Data

Figure 2: Dominant 60 Hz interference
Mission Requirements

Receive and store electric and magnetic field signals
- Picotesla for minimum magnetic field strength
- Millivolt/meter for minimum electric field strength

● Utilize magnetometer to record magnetic field direction
  - Record all three axes (x, y, z)

Store and record all data to onboard SD card
- Minimum ADC sampling rate of 100 kHz
- Use of 4 analog to digital channels
- Estimated total data will be around 500 MB which will be stored onboard the microcontroller’s SD card
Expected Results

Record 3-30 kHz signals from lightning discharges from around the world

Signals should slowly decrease in strength as we enter the upper atmosphere

See 60 Hz interference decrease as a function of time in signal analysis
Concept of Operations

Altitude

Beginning of Ionosphere
$ t \approx 1.3 \text{ min} $
Altitude: 75 km

Data Recording of Reflection Process
$ t \approx 2.8 \text{ min} $
Altitude: $ \approx 115 \text{ km} $

High Tumble Rate
$ t \approx 4.0 \text{ min} $
Altitude: 95 km

End of Orion Burn – Spin Rate Largest
$ t \approx 0.6 \text{ min} $
Altitude: 52 km

Comparative Ground Data
$ t \approx 5.5 \text{ min} $
Chute Deploys

-G switch triggered
-All systems on
-Begin data collection

Chute Deploys
$ t \approx 15 \text{ min} $
Splash Down

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# Functional Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrite rod and plate antennas shall be sensitive enough to pick up VLF EM wave spectrum.</td>
<td><strong>Demonstration</strong></td>
<td>Conduct ground testing during initial construction of payload.</td>
</tr>
<tr>
<td>The VLF EM wave data will be recorded and stored on a microSD card.</td>
<td><strong>Analysis</strong></td>
<td>Data will be analyzed through the use of FFTs to prove VLF EM wave signal.</td>
</tr>
<tr>
<td>The full system shall fit on a single RockSat-C deck.</td>
<td><strong>Inspection</strong></td>
<td>Visual inspection will verify this requirement</td>
</tr>
<tr>
<td>The system shall survive the vibration characteristics prescribed by the RockSat-C program.</td>
<td><strong>Test</strong></td>
<td>The system will be subjected to these vibration loads in June during testing week.</td>
</tr>
<tr>
<td>The full system shall weigh within the range of 19.8 to 20.2 lbs.</td>
<td><strong>Inspection</strong></td>
<td>System shall be put on a scale to determine weight.</td>
</tr>
</tbody>
</table>
Final Design Description

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Mechanical Changes since CDR

- New ferrite antenna model, as old one was taken off the StormWise website before we ordered one
- Consequence: Mounts tweaked for shorter antenna and thinner diameter
- New antennas can pick up the same range of frequency
Mechanical Changes since CDR

- New fastening method for antenna mount to makrolon plate: heat-set threaded inserts
  - Purpose: a metal screw threaded to a metal insert and heat-set to 3D printed plastic is less liable to disassemble by stress
- Will not affect other parts of the cannister or weight budget
Analog Changes since CDR

- Added Sallen-Key Filters
  - Help with signals around 3K or 30K Hz
- Rearranged filters
  - Fluctuate around 9V (0V for Op-amps)
- Design is now finalized
Digital Changes since CDR

- No significant system modifications.
Overall Functional Block Diagram
Mechanical FBD

- Ferrite rod antenna 1 → To preamp/filter
- Ferrite rod antenna 2 → To preamp/filter
- Ferrite rod antenna 3 → To preamp/filter
- Plate antenna → To preamp/filter
- 9-pin port-to-cannister connection

Antenna outputs
Analog FBD

- Wallops Early Activation
- Batteries
- Voltage Splitter
- Antenna Inputs
- Antenna Systems
  - Ferrite Rod Amp/Filter
  - Ferrite Rod Amp/Filter
  - Ferrite Rod Amp/Filter
  - Plate Antenna Amp/Filter
- Outputs to XMos

Legend:
- 18 V DC
- 9 V DC
- Ground
Mechanical Design:

- Present your FINAL mechanical design
  - Many views of your solid models (labeled)
  - These will be used for your pre-launch inspection by Wallops personnel in June/August
  - Updated Mass Budget
  - List of materials used in mechanical design
  - Address any Hazardous Mechanical items
Mechanical Design

Overview
Mechanical Design

Top layer

Data acquisition units
Support rods

Vertical rod support (Top)
Middle layer

Lower horizontal support

Higher horizontal support
Mechanical Design

Bottom layer

Battery packs

Vertical rod support (bottom)
### Detailed Mass Budget

<table>
<thead>
<tr>
<th>Part</th>
<th>Total Mass (lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrite Rods</td>
<td>3.0</td>
</tr>
<tr>
<td>Batteries</td>
<td>1.0</td>
</tr>
<tr>
<td>Makroloplates</td>
<td>1.0</td>
</tr>
<tr>
<td>Support Rods</td>
<td>1</td>
</tr>
<tr>
<td>Antenna Mounts</td>
<td>2.0</td>
</tr>
<tr>
<td>Can</td>
<td>6.6</td>
</tr>
<tr>
<td>Magnetometer, data</td>
<td>1.0</td>
</tr>
<tr>
<td>Preamps</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>19.9</strong></td>
</tr>
<tr>
<td><strong>Over/Under</strong></td>
<td><strong>(0.10)</strong></td>
</tr>
</tbody>
</table>
Hazardous Mechanical Items

• No hazardous materials
Finalized Electrical Design

Ferrite Rod Amplifier and Filter x3
Plate Antenna Amplifier and Filter x1

18V

9V
Early Activation and Voltage Splitter

![Diagram of Wallops Early Activation System with components labeled: V4, R8 1000, R9 1000, U1, LT1057, 18V, and 9V connections.]
9V from Op Amp to 1V for microcontroller
## Power Budget

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Voltage (V)</th>
<th>Max Current (A)</th>
<th>Time On (min)</th>
<th>Amp-Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>xMOS 1 (CDH)</td>
<td>5</td>
<td>0.2</td>
<td>20</td>
<td>0.06667</td>
</tr>
<tr>
<td>xMOS 2</td>
<td>5</td>
<td>0.2</td>
<td>20</td>
<td>0.06667</td>
</tr>
<tr>
<td>Op amps (EPS)</td>
<td>18</td>
<td>0.2</td>
<td>20</td>
<td>0.06667</td>
</tr>
<tr>
<td>SD Board 1</td>
<td>3.3</td>
<td>0.025</td>
<td>20</td>
<td>0.00833</td>
</tr>
<tr>
<td>SD Board</td>
<td>3.3</td>
<td>0.025</td>
<td>20</td>
<td>0.00833</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>3.3</td>
<td>0.000002</td>
<td>20</td>
<td>0.000001</td>
</tr>
<tr>
<td>STR and ADT</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>0.00000</td>
</tr>
<tr>
<td>Batteries (2 9V in series)</td>
<td>18</td>
<td></td>
<td>20</td>
<td>0.400</td>
</tr>
</tbody>
</table>

Total (A*hr): 0.2167

Total Power Capacity 0.400
Hazardous Electrical Items

Highest Voltage components are 18V from ground
Solder will keep PCBs held together in vacuum and at high accelerations.
   No foreseeable operational hazards
Software Design

xCORE 1

Start collecting data from loop antennas through ADC.

Data Buffer

Write to SD card in ten second intervals.

Repeat

If parameters not met.

If parameters met.

Power on microcontrollers at t -180 seconds.

Save data to micro-SD card

Check for mission end parameters.

Save data to micro-SD card

Check for mission end parameters.

Shutdown

Write to SD card in ten second intervals.

Repeat

If parameters not met.

If parameters met.

xCORE 2

Start collecting data from loop antennas and magnetometer

Data Buffer

Write to SD card in ten second intervals.

If parameters not met.

If parameters met.

Repeat
De-Scopes/Off-Ramps

- Off-Ramps
  - No off-ramps
- De-Scopes
  - No major issues that need to be treated as De-Scopes
Hardware Procurement Status

Adam, Nick, Garrett
Mechanical Elements

- We have purchased our heat-inset fasteners
- We have our final designs for the mounts, but do not have any printed except for a few now-broken test copies due to problems with the 3D printer
- Need to order cut makrolon plates and support rods, but have sources for those from last year’s project
- Have ferrite rod antenna
- Have not acquired plate antenna
The Othermill has been tested and was used to run a Hello World project
Designs can be imported from KiCAD, figuring out how to get correct layers to import
More operational amplifiers will be have to be ordered and tested before soldering them
The rest of the parts are in house
PCB is in 1st revision, still working on getting full design put into KiCAD
Software Elements

- Code to start collecting from ADC is complete.
- Code for data buffer is complete.
- Code to write to sd card is complete.
- Code to collect data from magnetometer is in progress.
- Code to check for mission end is in progress.
Subsystem Testing Results

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Subsystems Breakdown

Subsystem Teams

- EPS: Electrical and Power System
- CDH: Command and Data Handling
- STR: Structures and Antenna
EPS Status

Completed:
• Amplifier design
• Filtration design
• Early Activation design
• KiCAD and Othermill tutorials

Ongoing:
• KiCAD design
  – Copied from LTSpice
• Power supply to other subsystems

Not started:
• PCB milling of KiCAD design
EPS Testing

Design tested on Breadboard
• Both Loop antenna and Sine generator inputs
• Runs as expected and will meet mission requirements
Amplifier Testing Results

Input was noise from a loop antenna made last year. Gain of $10^5$. Main frequency is $\sim 160$ Hz.

Sampling from the output of second amplifier, Max and min voltages of $+5$ and $-5V$.

*Amplifiers were run at $-5V$ instead of $-9V$, as they will be...
Filter Testing Results

Filters mostly eliminate frequencies below 3 kHz, above 30 kHz

Same setup as previous slide, except sampling from after filter stages
KiCAD and Othermill testing

Tutorials
- Familiarization
- Can now transfer design to KiCAD and to Othermill to make a PCB

Design
- Working on recreating LTSpice simulation in KiCAD
- Have not transferred a completed design to Othermill yet
Completed Othermill “Hello World” program

Capable of making PCBs of the design once we figure out how to import it from KiCAD correctly

The “Hello World” program’s result in front of the Othermill machine
Output and Power Supply Testing

Output drops from 9V to 1V

Similar system needed with other systems that require power: 18V dropped to 5V for XMos, 3.3V for Magnetometer
CDH Testing

Completed:
• Read from ADC
• Data Buffer
• SD card write

Ongoing:
• Magnetometer read

Not Started:
• End of mission shutdown

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Magnetometer wiring & read
• Wired the startkit and magnetometer together.
• Initiate an I2C connections.
• Attempted to read data from magnetometer.
• Printed results to debug console.
CDH Testing

Magnetometer wiring and read
• After wiring the magnetometer to the xCORE I had software attempt to send 8-bit values to the magnetometer to initialize its start up.
• These values were successfully sent without error messages being returned.
• Next I tried to read values from the x,y,z value registers.
• The result were returned and printed to the debug console however they have thus far been inconsistent.
• This has lead me to believe that their is a problem in the startup parameters that i use, such as the gauss range it measures at, that are causing this.
STR/ADT Testing

Completed
• Antenna mount structural testing

Ongoing
• Heat inset fastener installation

Not Yet Started
• Fastening to makrolon
• Wire control
STR/ADT Testing

Structural Design Testing
• We went through a few iterations of tweaks on the antenna mounts, to ensure that the antennas fit and that the mounts were difficult to break under pressure
• Pictured are two of the early prototypes, one of them screwed into wood and broken to see how the fillets held up.
• Testing led to dropping the fillets and using the heat inset method instead of putting screws through solid portions of the printer filament
Heat Insert Testing

- We used a failed prototype to test heat-insertion of threaded nuts into filament.
- Our takeaway was that this was significantly more sturdy than a simple screw into the plastic, even when the heat-insert was held by a single plastic layer.
- We have yet to practice heat-insertion of nuts on a functional prototype.
Plan for Integrated Testing

Adam
Plan for Subsystem Integration

• Analog and Mechanical
  – Testing between antennas and electrical components
  – Physical integration of PCB with canister

• Analog and Digital
  – Connections from PCB to XMos kits

• Digital and Mechanical
  – Integration into canister

• Plan
  – Teams will need to meet up to coordinate testing
  – 1st meeting before 3/6
  – Preferably weekly from now until 3/27
Project Management

Adam
Team Organization Chart

Advisor: Dr. Brant Carlson

Team Lead: Adam Biewer

Analog Lead: Adam Biewer
- Mentor: Max Becher, Breonna McMahon

Digital Lead: Nicholas Poole
- Zac Birringer, Ariane Boissonnas

Mechanical Lead: Garrett Stepp
- Eric Schmitt, Trevor Wills, Chance Beaty

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## Contact Matrix

<table>
<thead>
<tr>
<th>RockSat-C 2016-2017 Contact Sheet (Carthage College)</th>
<th>Team Member</th>
<th>Email Address</th>
<th>Phone Number</th>
<th>US Person? (Y/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tom Shannon</td>
<td><a href="mailto:tshannon@carthage.edu">tshannon@carthage.edu</a></td>
<td>262-496-1711</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Ariane Boissonnas (Digital)</td>
<td><a href="mailto:aboisssonnas@carthage.edu">aboisssonnas@carthage.edu</a></td>
<td>608-514-6229</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Chance Beaty (Mechanical)</td>
<td><a href="mailto:cbeaty@carthage.edu">cbeaty@carthage.edu</a></td>
<td>970-819-7258</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Adam Biewer (Team Lead)</td>
<td><a href="mailto:abiewer@carthage.edu">abiewer@carthage.edu</a></td>
<td>262-337-2802</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Zac Birringer (Digital)</td>
<td><a href="mailto:zbirringer@carthage.edu">zbirringer@carthage.edu</a></td>
<td>(920) 905-4881</td>
<td>Y</td>
<td></td>
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<tr>
<td>Nicholas Poole(Digital Lead)</td>
<td><a href="mailto:npoole@carthage.edu">npoole@carthage.edu</a></td>
<td></td>
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<tr>
<td>Breonna McMahon(Analog)</td>
<td><a href="mailto:bmcmahon1@carthage.edu">bmcmahon1@carthage.edu</a></td>
<td></td>
<td>Y</td>
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<tr>
<td>Garrett Stepp (Mechanical Lead)</td>
<td><a href="mailto:gstepp@carthage.edu">gstepp@carthage.edu</a></td>
<td>(608) 287-6866</td>
<td>Y</td>
<td></td>
</tr>
</tbody>
</table>
Schedule

Mid-February- Start Subsystem Integration

3/6 Progress Update Telecom

Week of 3/20- Finish Integration

3/27 Integrated Subsystem Testing Review

We are on schedule to begin Integration Testing
<table>
<thead>
<tr>
<th>Requirement</th>
<th>Status/Reason (if needed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of gravity in 1&quot; mid-can?</td>
<td></td>
</tr>
<tr>
<td>Contained in can</td>
<td></td>
</tr>
<tr>
<td>Connected to can by 4/5 bulkheads on top and bottom only</td>
<td></td>
</tr>
<tr>
<td>Mass at 20±0.2lbs</td>
<td>19.7lb estimate</td>
</tr>
<tr>
<td>Shared canister clearance</td>
<td>Using Full Canister</td>
</tr>
<tr>
<td>No voltage on the can</td>
<td></td>
</tr>
<tr>
<td>Activation wires at least 4 ft</td>
<td>1.SYS.1, Still need to order</td>
</tr>
<tr>
<td>Activation wire at least 24 gauge</td>
<td>Same as above</td>
</tr>
<tr>
<td>Early Activation: current &lt; 1 A</td>
<td>400mA current maximum expected</td>
</tr>
<tr>
<td>T-0 Activation: current &lt; .1 A</td>
<td></td>
</tr>
<tr>
<td>Battery Type</td>
<td>NiMH Rechargeable</td>
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# Budget

<table>
<thead>
<tr>
<th>Item</th>
<th>Supplier</th>
<th>Estimated, Specific Cost</th>
<th>Number Required</th>
<th>Total Cost</th>
<th>Notes</th>
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<tbody>
<tr>
<td>XMOS StartKit Microcontroller</td>
<td>DigiKey</td>
<td>$15.00</td>
<td>2</td>
<td>$30.00</td>
<td></td>
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<tr>
<td>Ferrite Rod Antenna</td>
<td>Stormwise</td>
<td>$49.95</td>
<td>3</td>
<td>$150.00</td>
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<tr>
<td>Printed Circuit Boards</td>
<td>To be manufactured</td>
<td>$30.00</td>
<td>3</td>
<td>$90.00</td>
<td>3 board revisions (including components)</td>
</tr>
<tr>
<td>Electrical Plate Antenna</td>
<td>To be manufactured</td>
<td>$40.00</td>
<td>1</td>
<td>$40.00</td>
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<td>SD adapters</td>
<td>DigiKey</td>
<td>$10.00</td>
<td>2</td>
<td>$20.00</td>
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<tr>
<td>microSD cards</td>
<td>Amazon</td>
<td>$10.00</td>
<td>2</td>
<td>$20.00</td>
<td></td>
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<tr>
<td>Batteries</td>
<td>Digikey</td>
<td>$15.00</td>
<td>4</td>
<td>$60.00</td>
<td></td>
</tr>
</tbody>
</table>

Total (no margin): $410.00

Total (w/ margin): $512.50

---

Margin: 0.25  
Budget: $500.00  
Last Update: 2/12/2017

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**VLF Radio Receiver**
Worries and Concerns

- Integration testing will take longer than expected
  - Start planning as soon as possible
- Transportation Funding
  - Working with Student Government for Funding
Conclusion

We are currently on track for getting each subsystem integrated and testing from each subsystem went well. With all major design and prototyping elements completed, we are now shifting our focus on linking up the subsystems for further testing.