PolarCube

University of Colorado at Boulder

COSGC Symposium

April 18th, 2015

Glenda Alvarenga
Christopher Rouw
PolarCube will perform tropospheric temperature sounding using the 118.7503 GHz $\text{O}_2$ resonance, by using a radiometer.

Mission Statement

Create a 3D temperature profile of the lower atmosphere.
Primary Scientific Objectives

- Temperature sounding using the 118.7503 GHz O₂ resonant frequency
- Study of ice retreat in Polar regions on a CubeSat form factor

Secondary Science Objectives

- Mesoscale weather research
- Storm cell observations
- Hurricane warm core behavior
- Terrestrial temperature detection with 15-20 km spatial resolution
**Frequency Significance**

118.7503 GHz O2

- Less sensitive to H₂O (penetrates cloud cover)
- Vertical resolution of 0-30 km
- Feasible for a CubeSat form factor

Opacity plot of microwave frequencies and resonant responses
UNP Participation

University Nanosat Program

• UNP Objectives
  – Train future space professionals
  – Rigorous 2-year concept-to-flight-ready spacecraft competition
  – Small Satellite research and development (R & D)

• Administered by
  – AFOSR
  – AFRL
  – AIAA

UN5- DANDE Spin Test

UN8- PolarCube at the UNP FCR
Military Relevance

Air Force Weather Agency (AFWA)
- Dr. Jeff Cetola (16WS/WXE)
- Letter of Support: “Complement DMSP Programs… serve AFWA well in various models through assimilation and algorithms”

Air Force Research Labs (AFRL) Kirtland AFB
- John Roadcap (RVB)
- Letter of Support: “Potential to improve weather forecasting”

National Ice Center (NIC)
- Chief Scientist Dr. Pablo Clemente
- Letter of Support: “Low-cost solution to improve observational and communication capabilities”
Heritage & Design Evolution

- 3U CubeSat based on ALL-STAR concept
- Miniaturized, previously flown radiometer
  - MTS NASA ER-2 1986
  - Rotating mirror
8 Channels Centered at 118.7503 GHz

Radiometer Channels
Channel 1
Channel 2
Channel 3
Channel 4
Channel 5
Channel 6
Channel 7
Channel 8

Off-Center IF Frequencies
0.2 GHz
0.4 GHz
0.7 GHz
1.1 GHz
1.5 GHz
2.1 GHz
3.1 GHz
5.0 GHz

3D Temperature Profile of Atmosphere from MiniRad Data

Radiometer FOV
Troposphere
0 km - 20 km
Earth Surface

15 km – 20 km Spot Size
Sub-Track Data sampling

- Function of temperature & altitude
- Each channel corresponds to different frequency

8 Channels Centered at 118.7503 GHz
MiniRad Design

• Comprised of three subsections
  – Radio Frequency
  – Intermediate Frequency
  – Digital
MiniRad Design

- Senses brightness temperature

Radio Frequency

- 150K to 310K

Corrugated Feedhorn

PIN Attenuator VCVA-98
Isolator WR-8 SIWN12-1
Harmonic Mixer VDI SHM-WRB
Low Noise Amplifier AFS3-00100200-10-15P-4

Thermistor
Parabolic Reflecting Mirror

PIN Control

Local Oscillator Spacek GV-593 59.375 GHz

Corrugated Feedhorn
Reflective Pin Diode Switch
Isolator
Subharmonic Mixer
3x multiplier
3D Printed Antenna Subsystem

• **Advantages:**
  – Low cost compared to traditional manufacturing
  – Quick turn-around time.

• **Challenges:**
  – Internal corrugations (grooves)
  – Surface roughness requirements $\lambda/100$

• **Resolution:** Model feedhorn (HFSS) to account for:
  – Effects of surface roughness
  – Manufacturing capabilities in design
  – Measure antenna pattern at NIST
  – Validate with theoretical performance
MiniRad Design

- Frequency is mixed down to 0.2-5.0 GHz
- 8 Channel design to maximize range
MiniRad Design

- Designed to interface to ALL-STAR standard design
MiniRad Payload

118.7503 GHz Radiometer
- Microwave frequency
- O₂ Resonance
- Rotating Parabolic Mirror
- 16.5 km ground spot size (410 km orbit altitude)
- Cloud Penetrating Frequency
  - Thick clouds = 30% attenuation
Mission Data Plan

- Data received and archived by PolarCube Mission Operations Team at CU
- **Metadata processed at NSIDC**
  - NSIDC Maintains DMSP Data Sets
- **Standard Data Format Usable by AFWA**
  - Dr. Jeff Cetola Chief, Environmental Characterization Flight
  - Applicable to atmospheric emissivity models
  - Detailed data plan in progress

**PolarCube Earth Station 2014**

**Radar Earth Station Team**

**COSGC MOPS Team 2014**

**“Green” HVAC System at NSIDC**
Leveraging ALL-STAR/THEIA

ALL-STAR Student Experience

- System Integration and Testing
- Protoflight Vibe (3 dB) Testing
- TVAC/Bakeout Testing
- CalPoly P-POD Integration, satisfied ELaNa ICD
- Launch Readiness Review
- Completed all licensing (NOAA, FCC, IARU)
- Mature Ground System Architecture

Launched on CRS-3 F9  
April 18, 2014
System Overview
System Overview

CDH
- ARM A5 Cortex Processor
- Multiple communication busses
  - SPI
  - I2C
- Ethernet LAN
- JTAG Programmer

FSW
- Server based architecture
- Linux OS
System Overview

EPS
- Li-Ion battery pack
- 4 MPPTs
- 3.3V and 12V
- Houses all inhibits
System Overview

- **COM**
  - FPGA plus RF SOC
  - S-Band downlink 2400 MHz @250 kbps (min)
  - UHF uplink/downlink 435 MHz @9.6 kbps
System Overview

ACS
- SAM 4E Cortex Processor
- 3-axis stabilized
- Sensors
  - Star Camera
  - Magnetometer
  - Gyroscope
PolarCube Silver Boards

All hardware is completely designed, built and tested by students!
PolarCube Silver Boards

Subsystem Primary Boards
PolarCube Silver Boards

Subsystem Primary Boards
Silver-FCR Hardware

RAD Structure

RAD Structure Deployed

Integrated Systems
PolarCube Team

• Student led interdisciplinary team
• Satellite build/delivery experience
• Industry and Academic experts “Active Mentoring”
  • Experienced advisors for different disciplines
  • Current students, alumni, faculty, industry
  • Collaboration with NIST for scientific instrument verification

PolarCube 2015 Team at FCR

DANDE Micro-satellite delivered and launched; operation from 9/2013 - present

ALL-STAR-THEIA 3-Axis stabilized 3U CubeSat delivered and launched
Thank You!

http://spacegrant.colorado.edu/polarcube
BACKUP CHARTS
Military Relevance

Current Assets:

- Defense Meteorological Satellite Program (DMSP)
  - (1970’s-Present) DoD sent data to Air Force Weather Agency for real-time weather forecasting
  - Single, high-cost satellite increases severity of instrument loss
- AMSR-E: Advanced Microwave Sounding Radiometer

Current Needs:

- More accessible, low-risk platforms
- Small platforms that compliment current technology
- Cloud penetrating temperature profiling
- Empirical data for atmospheric emissivity models

DMSP image of Hurricane Rita 9/22/05 (left) and LMCO DMSP-19, final integration Vandenberg AFB (right)
Military Relevance

• **PolarCube** compliments current assets and provides higher spatial resolution (15-20 km) on a small, CubeSatellite platform
  - DMSP Spatial Resolution 175-38 km & AMSR-E Spatial Resolution 30 km

• **Science Advisory Board-MMA**
  - Category A weather requirements
  - “Mission areas with greatest potential are… weather missions with a Microwave Imager Sounder microsat program” – SAB MMA 2014

• **Air Force Tech Horizons 2010-2030:**
  - “Fractionated Systems”
  - NRC Decadal Survey – PolarCube as a PATH array constellation

<table>
<thead>
<tr>
<th>TN ID</th>
<th>TN Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>839</td>
<td>Advanced characterization of <strong>terrestrial environment</strong> variables to support military operations.</td>
</tr>
<tr>
<td>850</td>
<td><strong>Terrestrial weather</strong> effects products</td>
</tr>
<tr>
<td>951</td>
<td>Advanced <strong>terrestrial weather</strong> models/applications</td>
</tr>
<tr>
<td>992</td>
<td>Exploitation of non-traditional sources for <strong>terrestrial weather</strong> monitoring</td>
</tr>
</tbody>
</table>

*FY17 S&T Guidance Process Addressed Technology Needs by PolarCube*
## RAD Requirements

<table>
<thead>
<tr>
<th>REF ID</th>
<th>Requirement</th>
<th>Ver. Method</th>
<th>Ver. Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.RAD.0</td>
<td>MiniRad shall have a NE(\Delta)T resolution better than 0.5 K for the surface sensing channels at FWHM resolution.</td>
<td>Analysis</td>
<td>To be ver.</td>
</tr>
<tr>
<td>2.RAD.1</td>
<td>MiniRad shall have a NE(\Delta)T resolution better than 2 K for the highest altitude sensing channels at FWHM resolution.</td>
<td>Analysis</td>
<td>To be ver.</td>
</tr>
<tr>
<td>2.RAD.3</td>
<td>MiniRad shall provide vertical temperature profile measurements with an RMS accuracy of better than 2 K from 1 km to 20 km altitude.</td>
<td>Analysis</td>
<td>To be ver.</td>
</tr>
<tr>
<td>2.RAD.4</td>
<td>MiniRad shall have a 3dB spot diameter at nadir of 16.5 km (+- 1.65 km) based on a orbital altitude of 410Km</td>
<td>Analysis</td>
<td>To be ver.</td>
</tr>
<tr>
<td>2.RAD.6</td>
<td>MiniRad shall have a 3dB spot diameter at nadir of 16.5 km (+- 1.65 km) based on a orbital altitude of 410 km</td>
<td>Testing</td>
<td>To be ver.</td>
</tr>
<tr>
<td>2.RAD.7</td>
<td>MiniRad shall have an along track sampling factor of at least 2.54 times the full-width half-maximum footprint at nadir.</td>
<td>Testing</td>
<td>To be ver.</td>
</tr>
<tr>
<td>2.RAD.12</td>
<td>MiniRad shall acquire science data during at minimum 15 minute segments.</td>
<td>Testing</td>
<td>To be ver.</td>
</tr>
</tbody>
</table>
Feedhorn Pattern Validation at NIST

The feedhorn will be characterized at the new National Institute of Standards and Technology (NIST, Boulder, CO) robotic antenna characterization facility, CROMMA.

• Near-field data
  – Acquired for the feedhorn
  – Feedhorn-reflector system

• Comparison
  – Measured results
  – Theoretical antenna patterns computed using the analysis previously outlined.

• Antenna probe position to within 25 μm over a spherical scan
• Better than 0.01° pointing accuracy over entire near-field scan
• At 118.75 GHz, it is possible to achieve a positioning accuracy of ~λ/100 and hence measure a highly accurate antenna pattern.