Low Cost Rapid Response Spacecraft, (LCRRS) –
A Research Project in Low Cost Spacecraft Design and Fabrication in a Rapid Prototyping Environment

Small Satellite Conference,
Session IV: New Systems Concepts
August 12, 2008

Stevan Spremo
COTSAT Project Manager, Small Spacecraft Division
NASA-Ames Research Center
Moffett Field, CA 94035-1000
650-604-4128; Stevan.M.Spremo@nasa.gov
CheapSat (Low Cost Rapid Response System LCRRS)
Cost Comparison to Long-Term High Reliability Missions
6 Month Mission Lifetime • 450 Kg

$2.5 Million
Development, Parts & Labor

PROS
- Characterized by cheap, rapid development
- Able to achieve many NASA missions that have short mission lifetime (LEO) for low cost
- Enables missions that are otherwise not likely to happen
- Appropriate for new class of low cost launch vehicles (example: SpaceX, Falcon 1)
- Developing new capability for Space Robotics
- Able to fly biological freeflyers
- Able to be reconfigured

CONS
- Reduced reliability
- Limited to LEO
- Short mission life
- Not radiation hardened
- Not capable to do planetary missions

Commercial Off-The-Shelf Reduces Price

Ames Reaction Wheel
$12,000
Compared to $150,000+
Rated for Space Vacuum

LIon Batteries
$4,500

PC 104 Computer
$12,000

Advanced Circuitry
$50,000

LIbera IMU
$12,000

Star tracker
$17,000 x 4 Units

Forward (FWD) End Plate
$33,000
Pressure Vessel Including a Secondary Structure

SMALL Optical Telescope with Mods
$150,000

SMALL Solar Array Assembly COTS Option A
$12,000

Canon SLR 12 Megapixel Camera
$5,000

Radio ISM band
$3,500

(Aft) End Plate
$14,000

Development, Parts & Labor

$12,000

IMU
$12,000

FWD End Plate
$14,000

Cheapsat

National Aeronautics and Space Administration

Project Manager Stevan Spremo • sspremo@mail.arc.nasa.gov

www.nasa.gov
Understanding the Role of the **Extended Red Emission** in the Interstellar Medium

This dull red glow is associated with reflection nebulae, carbon-rich planetary nebulae, HII regions, and the diffuse interstellar medium of the Milky Way Galaxy.

Evidence indicates that the ERE carrier is carbon-rich, ubiquitous, abundant, and is fundamentally important to both astrobiology and understanding evolution of the ISM.

From the ground, the night sky brightness is dominated by highly variable airglow, making it impossible to image the ERE in faint sources.

**Payload:**
- SBIG ST-9XEI
- CFW9 Filter Wheel
- Nikon 85mm f/1.8 lens

Components contributing to night sky brightness, which prevents imaging ERE from the ground in faint sources, are shown as a function of \( \lambda \).

(Adapted from Leinert et al. (1997)).

Extinction map (from IRAS 100 \( \mu \)m data) of the HI cloud G90.0+38.8. This image is the same size as one frame from the COTSAT camera, but the spatial resolution will be six times better.
Operating Modes

- **Data Acquisition**
  Slew over target area, acquire payload data, provide onboard data compression and preprocessing

- **Ground Communications**
  Point toward ground station, upload data to ground station, transceiver telemetry, perform diagnostics

- **Battery Charging**
  Slow axial rotation to prevent temperature differential across satellite while batteries charge

- **Desaturation**
  Torque coils are used to desaturate the reaction wheels
Instrument Integration:
- External volume: 26” X 26” X 60.5”
- Internal volume: 23” X 23” X 8.25”
- Data interfaces: USB 2.0, Serial (Analog/TTL/RS232), PC/104-Plus, Parallel LPT1, E-IDE, Ethernet
- Endcaps provide #10-32 standard bolt pattern w/ 1.5” pitch
The COTSAT primary structure will consist of billet aluminum endcaps with a welded aluminum-sheet core, utilizing marmon-clamp & o-ring interfaces.

Modular internal structure allows for quick and easy sub-system testing and integration.

Parameters:
- Endcaps ~ 9 kg
- Structure Core ~ 16 kg
- 23.25” Bolt Circle Separation System
- ~1 Atmosphere Artificial Environment
- Dimensions:
  - 28.8”W X 30.6”D X 27.3”H w/o Solar Array
  - 46.9”W X 42.1”D X 102.5”H w/ Solar Array & Antennas
Attitude Determination and Control System (ADACS)

- **Actuators:**
  - 4 Reaction Wheels
    - Pyramidal Configuration
    - In-House Design and Fabrication
  - 3 Torque Coils
    - In-House Design and Fabrication
- **Sensors:**
  - 1 GPS Receiver
  - 4 Star Trackers
    - Algorithm Developed In-House
    - Lumenera Commercial Machine Vision Cameras
  - 2 Microstrain Inertial Measurement Units
  - 1 Digital 3-Axis Fluxgate Magnetometer

**Specifications:**
- 3-Axis Controlled
- Attitude Accuracy 35 arcsec
- Jitter ~5 arcsec/sec
- Slew Rate > 60 deg/min
Cost-Optimized Test of Spacecraft Avionics & Technologies
Command and Data Handling (C&DH) and Communications

- PC-104 architecture with 8 Gb onboard memory
- Linux-based soft-realtime OS
- SpaceQuest S-Band Transmitter
- Downlink data rate of ~1 mbps
- 2.0W RF transmitted, 3.0 dB margin - TBD

- 300 km circular orbit
- 34.0° inclination
- Minimum of two contact periods per orbit
- Estimated contact time of 5 minutes
Electrical Power System

- 1 Battery Board
  - Monitors charge
- 3 Commercial Charge Controllers
  - Control battery charge from SA
  - Prevent overcharge of battery
- 18 Kyocera COTS Solar Arrays
  - ~$10.00 per Watt
  - Modified COTS (MOTS)
- GeneSat-1 heritage electrical system architecture

- 4 Lithium Battery Packs
  - Provides 52.8 A·hr
- Up to 32 Remote Power Controllers (RPCs)
  - Measure and regulate voltage
  - Measure and limit current
  - Monitor power consumption
  - Latch Up Mitigation
- 1 Central Power Controller (CPC)
  - PC-104 form factor
Communications

- Beacon
- uHard MHX-2420
- Santa Clara University Contracted to conduct all ground station support for all radios
- All radio systems selected have flight heritage on both ground station and spacecraft

### Link Budget COTSAT Radios

<table>
<thead>
<tr>
<th>Item</th>
<th>Symbol</th>
<th>Units</th>
<th>S-band Down</th>
<th>MHX Down</th>
<th>MHX Up</th>
<th>Beacon Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit Altitude (km)</td>
<td>km</td>
<td>450</td>
<td>450</td>
<td>450</td>
<td>450</td>
<td></td>
</tr>
<tr>
<td>Elevation Angle</td>
<td>deg</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>f GHz</td>
<td>2.2</td>
<td>2.4</td>
<td>2.4</td>
<td>0.4371</td>
<td></td>
</tr>
<tr>
<td>Transmitter Power</td>
<td>P Watts</td>
<td>2.5</td>
<td>1</td>
<td>1</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Transmitter Line Loss</td>
<td>dBW</td>
<td>4</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Transmitter Efficiency</td>
<td>dB</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>-2</td>
<td></td>
</tr>
<tr>
<td>Avg Transmit Antenna Gain</td>
<td>G_t</td>
<td>dB</td>
<td>17.5</td>
<td>3</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Transmit Total Gain</td>
<td>G_r</td>
<td>dB</td>
<td>16.5</td>
<td>2</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Eq. Isotropic Radiated Power</td>
<td>EIRP</td>
<td>dB</td>
<td>20</td>
<td>2</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Propagation Path Length</td>
<td>S</td>
<td>km</td>
<td>1570</td>
<td>1570</td>
<td>1570</td>
<td></td>
</tr>
<tr>
<td>Space Loss</td>
<td>L_s</td>
<td>dB</td>
<td>-164</td>
<td>-164</td>
<td>-149</td>
<td></td>
</tr>
<tr>
<td>Propagation and Polarization</td>
<td>L_p</td>
<td>dB</td>
<td>-3</td>
<td>-3</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>Receive Antenna Diameter</td>
<td>D</td>
<td>m</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Receive Antenna Eff</td>
<td>η</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Peak Receive Antenna Gain</td>
<td>G_p</td>
<td>dB</td>
<td>34.2</td>
<td>35.0</td>
<td>35.0</td>
<td></td>
</tr>
<tr>
<td>Receive Antenna Line Loss</td>
<td>L_r</td>
<td>dB</td>
<td>-0.5</td>
<td>-0.5</td>
<td>-0.5</td>
<td></td>
</tr>
<tr>
<td>Receive Antenna Beamwidth</td>
<td>θ deg</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>Receive Antenna Efficiency</td>
<td>E deg</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>RX Antenna Pointing Error</td>
<td>L_p</td>
<td>dB</td>
<td>-0.3</td>
<td>-0.4</td>
<td>-0.4</td>
<td></td>
</tr>
<tr>
<td>Receive Antenna Gain with pointing error</td>
<td>G_r</td>
<td>dB</td>
<td>33.1</td>
<td>34.1</td>
<td>31.4</td>
<td></td>
</tr>
<tr>
<td>System Noise Temperature ***</td>
<td>T_s</td>
<td>K</td>
<td>300</td>
<td>385</td>
<td>850</td>
<td></td>
</tr>
<tr>
<td>Eb/No Data Rate</td>
<td>R bps</td>
<td>140000</td>
<td>86000</td>
<td>86000</td>
<td>1200</td>
<td></td>
</tr>
<tr>
<td>Eb/No Bit Error Rate</td>
<td>BER</td>
<td>10-5</td>
<td>10-5</td>
<td>10-5</td>
<td>10-5</td>
<td></td>
</tr>
<tr>
<td>Required Eb/No ****</td>
<td>Req Eb/No</td>
<td>dB-Hz</td>
<td>10</td>
<td>13.5</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>Implementation Loss</td>
<td>dB</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td></td>
</tr>
<tr>
<td>Margin</td>
<td>dB</td>
<td>17.0</td>
<td>5.2</td>
<td>15.6</td>
<td>10.0</td>
<td></td>
</tr>
</tbody>
</table>

* Equations are from [10]. Spreadsheet assumes zenith pass of S/C. 
** Assumes Ground antenna is parabolic
*** Rx noise temp=300K (Estimated)
**** GMSK Req=10dB
Current Status and Schedule Milestones

- Radios Selected (Beacon, uHard, SpaceQuest)
- Payload Selected
- Pressure Container Testing – Complete
- Pressure Container Leak Testing – 8/2008
- Radio Ground Station Selected
- Star Tracker Final Testing – 8/2008
- Solar Array Testing – 8/2008
- Star Tracker Final Test 8/2008
- Solar panel build 8/2008
- Control System Final Testing – 9/2008
- Flight wiring and harnessing – 9/2008
- Final Avionics integration - 10/2008
- Environmental testing 10/2008 -12/2008
- Software integration and test 8/2008 -12/2008
- Payload integration and testing 7/2008 – 10/2008
- Reaction Wheel Final Test 9/2008
- Torque Coils Final Test 10/2008
- Qualification testing 11/2008 – 12/2008
- Radio Licenses Completed/Issued – 12/2008
- Tested Flight Software Upload 1/2009
- Launch March 2009
Quick Facts:

• >6 months mission
• 385 kg total mass
• 113 W peak, 75 W average
• 300 km, 34.0 deg incl.
• 35 arcsec pointing accuracy
• ~5 arcsec/s jitter
• >60 deg/minute slew rate
• ~1 mbps downlink data rate

Satellite Projected Final Cost for Parts and Labor:
USD 4,120K

COTSAT currently has a staff of 7 FTE’s