CONSTRUCTING A CONSTELLATION OF 6U SOLAR POWER CUBE SATELLITES

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Overview

- Background

- Constructing a 6U SPCS
  - Mechanical Specifications
  - Electrical Power System
    - Power Generation/Sources
    - Energy Storage System
    - SPCS Payload
      - DC-to-RF Conversion System
      - Transmitting antenna system

- Constellation Design

- Legal/Political Considerations

- Conclusion and Future Work
**BACKGROUND**

- **CubeSats**
  - Concept developed in 1999 by Robert Twiggs at Stanford University and Jordi Puig-Suari at the California State Polytechnic University.
  - Idea allowed those with limited experience in the design of space missions to learn about spacecraft design and *unleash* spacecraft design ideas and concepts without the historical restrictions imposed by risk management for high-cost missions.
  - CubeSats have proven to be a cost effective form factor for getting payloads into orbit quickly and inexpensively.
  - CubeSat have been utilized by:
    - Universities
      - 196 missions-University Class
      - 98 different institutions
    - Commercial entities
    - Military

http://olson.skc.edu/cubesat/
Solar Power Satellites

- Concept patented 1973 by Peter Glaser (Author D. Little Company).
- Method and Apparatus for Converting Solar Radiation to Electrical Power
- Pioneering technical work on Microwave Wireless Power Transmission was performed by William Brown (Raytheon Company) starting in 1950s.
CONSTRUCTING A 6U SPCS

- **Mechanical Specifications**
  - Mass under 12kg
  - Size 12 cm X 24 cm X 36 cm
  - Structure made purely of welded 6061 aluminium sheeting

- **Electrical Power System (EPS)**
  - **Power Generation/Sources**
    - Eight-segmented solar panel system deployed (four per side).
    - Surface Area for individual solar panel is 22 cm X 35 cm (total: 0.6160 m²).
    - Solar cell efficiency rated at 28.3%.
    - $P_{BOL}$ of 18.75W (total: 150W) at 28 degrees Celsius.
    - $P_{EOL}$ is 113.475 W/(0.616m²) with a 10 year mission lifetime.
- Energy Storage System (ESS)
  - Two Lithium Ion (Li-Ion) rechargeable battery packs (total: 60Whr).
    - Highest capacity/mass ratio
    - Depth-of-discharge in LEO is 20%-40%
  - Used for initial solar panel deployment and to support operations.
  - 90% transmission efficiency between the battery and load.

- DC-to-RF Conversion System
  - DC-to-RF converter
  - Traveling wave tube amplifier (TWTA)
    - TWT electronic power conditioner (EPC)

- Power Management
- Transmitting antenna system
  - Pyramidal horn antenna
  - Gain of 18dBi
  - Frequency of 12GHz was selected

\[
P_r = P_t \left( \frac{\lambda}{4\pi R} \right)^2 D_{\text{max, } r} D_{\text{max, } t}
\]

\[P_r \equiv \text{Received Power} = 28.87 \text{mW}\]
\[P_t \equiv \text{Transmitted Power} = 72.25 \text{W}\]
\[\lambda \equiv \text{Wavelength} = 2.5 \text{cm}\]
\[D_{\text{max, } t} \equiv \text{maximum directivity of transmitter} = 63.1\]
\[D_{\text{max, } t} \equiv \text{maximum directivity of receiver} = 1000\]
\[R \equiv \text{source-to-receiver distance} = 25 \text{m}\]
\[
A_{phy,r} = \left( \frac{\lambda^2}{4\pi} \right) D_{max,r}
\]

\[
e_{app,r}
\]

\[
A_{phy,r} \equiv \text{Aperture receiver size} = 828.932 \ cm^2
\]

\[
e_{eff,r} \equiv \text{Aperture receiver efficiency} = 60\%
\]

• Increase the gain (30-40 dBi)
  • Deployable or inflatable reflecting antenna
• Planar flexible substrate array
• Integrate antenna system into the solar arrays
• External receiver system or one embedded in the body Of the spacecraft.
• Thermal
  • Thermal energy harvesters

• Attitude Determination and Control
  • Pointing accuracy to target receiver

• Communications
  • Receiving ground station commands
  • Transmitting craft status/performance updates
  • Coordinating between other SPCS
  • Receiving subscriber notifications

• Sensors and Bus
  • The bus interconnects all components
  • Sensor system utilizes sun and star tracker equipment to determine the precise position and orientation of the spacecraft

• Onboard computing
  • Spacecraft command and control
  • Processing subscription requests
  • Performing planning to determine how subscribers will be served
  • Determining attitude and position, based on sensor data
  • Deriving maneuvers to change attitude and position
  • Cluster command and planning

• Guidance and Navigation
  • Used for orbital corrections

• Propulsion
  • Electric propulsion system

http://www.aerospaceguide.net/rocketengines/electric_propulsion.html
<table>
<thead>
<tr>
<th>Component</th>
<th>Mass (kg)</th>
<th>Dimensions(cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar panels</td>
<td>2.72 (8 panels)</td>
<td>22x35x0.4</td>
</tr>
<tr>
<td>EPC</td>
<td>1.05</td>
<td>17.8x8.0x9.5</td>
</tr>
<tr>
<td>TWT</td>
<td>0.695</td>
<td>30x7.9x6.9</td>
</tr>
<tr>
<td>Li-Ion Batteries</td>
<td>0.512 (2 packs)</td>
<td>9.017x9.5885x2.3815</td>
</tr>
<tr>
<td>Horn antenna</td>
<td>0.23</td>
<td>12.852x7.849x5.949</td>
</tr>
<tr>
<td>Communications</td>
<td>0.9</td>
<td>9.6x9.0</td>
</tr>
<tr>
<td><strong>Total Mass</strong></td>
<td><strong>8.667</strong></td>
<td></td>
</tr>
</tbody>
</table>
The designed of constellation will be based on a model including initial and prospective SSP customers.

Clusters of SPCS placed throughout LEO forming a constellation.
• **Launch and Deployment**
  
  • Most widely used deployment system for CubeSats is the Poly-Picosatellite Orbital Deployer (P-POD).

• **Ground Stations**
  
  • Multiply ground stations
  
  • Utilize Earth stations based on amateur radio designs (commercial license)
  
  • Operating solution will come from the FCC.
  
  • Software developed to support commanding the spacecraft and decoding its beacon signals.

LEGAL/POLITICAL CONSIDERATIONS

- Presuming U.S. ownership/control licensing of the spacecraft will fall under the jurisdiction of the FCC.

- The FCC has adopted changes to the Experimental Radio Service. “A more flexible framework to keep pace with the speed of modern technological change, while continuing to provide an environment where creativity can thrive.”

- Outer Space Treaty of 1967 (Article IX) states that “state parties to the treaty shall conduct exploration of [space and celestial bodies] so as to avoid their harmful contamination.”
CONCLUSION AND FUTURE WORK

- 6U CubeSats have been presented that could prospectively change the nature of the design and operations of spacecraft.
  - Instead of self-contained power generators, consumers could procure power from a utility provider, paying for this power on an as-needed basis.
  - Spacecraft developers may avoid having to develop elaborate power generation capabilities based on the highest possible load needed.
  - May reduce mass and volume of spacecraft by removing power generation hardware.

- A space power utility may be the “next step” towards more effective use of space.
  - Detailed design, development and deployment of a 6U SPCS and a space-to-space power transfer test mission.
  - Look at 12U and 27U CubeSats models.
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THANK YOU!

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