Overview of Project SPATIUM – Space Precision Atomic-clock Timing Utility Mission

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SPATIUM Program

Space Precision Atomic-clock Timing Utility Mission

spatium (from Latin) - space, track, interval, time, duration

Joint Collaboration:

Research Objective:

- Ultimate goal is to develop a reliable platform for near real-time ionosphere plasma monitoring with excellent spatial and temporal resolutions

A mission the requires highly precise and stable timing reference on-board nanosatellites
SPATIUM Program

Modeling of the ionosphere plasma density using a combination of multipoint measurement of phase-shift in satellite clock signal and in-situ plasma density measurement from a constellation of nanosatellites.

Key Enabling Technologies:

- Constellations of CubeSats at different altitudes of LEO.
- High precision time reference (Chip-Scale Atomic Clock).
- Advanced Double Langmuir-probe for in-situ plasma measurement
- Spread-spectrum (SS) modulation and demodulation of satellite transmission signal.
- Time-synchronization of multiple CubeSats and ground stations
The Pathfinder - SPATIUM-I Mission

- SPATIUM-I is the first effort to validate a few key enabling technologies in low earth orbit:
  - In-orbit demonstration of Chip-Scale Atomic Clock (CSAC) as reliable reference clock for CubeSat;
  - In-orbit demonstration of transmission and receiving of dual UHF band (401MHz and 467MHz);
  - In-orbit demonstration of transmission of spread-spectrum (SS) modulated UHF signal with CSAC as a clock source;
  - Demodulation of spread-spectrum (SS) modulated satellite signal at ground stations;
  - Time-synchronization of multiple ground stations.
- The success of SPATIUM-I and the developed capabilities provide a strong fundamental for future missions.
SPATIUM-I CubeSat Design

- Generic 2U CubeSat design (dimension: 22.7cm x 10cm x 10cm and weight: 2.612 kg)
- Strictly adhere to the requirements of the Japanese Experiment Module (JEM) Small Satellite Orbital Deployer (J-SSOD) for deployment from ISS.
- The satellite used “harness-free” approach - a backplane board (BPB) was designed to electrically connect all subsystems together.

- Two deployable UHF monopole antennas for data transmission at two different UHF frequencies (401 MHz and 467 MHz).
Example of Conventional Timing References

**Hydrogen Maser (MHM 2010)**
- Volume: \(\approx 370,000 \text{ cm}^3\)
- Weight: 216 kg
- Power Consumption: 75 W
- Stability @ \(\tau=1\text{s}\): 1.5E-13

**Cesium Frequency Standard (5071A)**
- Volume: \(\approx 30,000 \text{ cm}^3\)
- Weight: 30 kg
- Power Consumption: 50 W
- Stability @ \(\tau=1\text{s}\): 1.2E-11

**Rubidium Oscillator (XPRO)**
- Volume: \(\approx 455 \text{ cm}^3\)
- Weight: 0.5 kg
- Power Consumption: 10 W
- Stability @ \(\tau=1\text{s}\): 1E-11

**Chip Scale Atomic Clock (SA.45s CSAC)**
- Volume: < 17 cm\(^3\) (4.06 cm x 3.53 cm x 1.14 cm)
- Weight: < 35 g
- Power Consumption: < 0.12 W
- Stability @ \(\tau=1\text{s}\): 3E-10

Microsemi Quantum™ SA.45s CSAC

- CSAC is a DARPA MTO-funded effort to produce accurate timing sources for portable instruments.
- Symmetricom (acquired by Microsemi) launched the world’s first commercially available CSAC in 2011.

Simplified Block Diagram

The Physics Package Design

Physics Package in LCC

Vacuum-sealed Physics Package

CSAC Mission Board Design

- CSAC is the main payload for SPATIUM-I mission.
- The main objective is to output precise clock signal throughout the satellite mission.
- The board is separated into two parts:
  a) CSAC Mission Board: output precise CSAC 10MHz clock signal, 1 PPS signal and other operation data to COM
  b) Supercapacitor Board: power back-up for CSAC board operation

### Specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>86.3mm x 90mm x 21mm (Compliance with J-SSOD requirement)</td>
</tr>
<tr>
<td>Weight</td>
<td>113 g</td>
</tr>
<tr>
<td>Voltage Supply</td>
<td>4.5 V</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>0.35 W</td>
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<tr>
<td>Warm Up Time</td>
<td>&lt; 180 s</td>
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</tbody>
</table>
| Data Interface with COM | CSAC data: UART serial communication. Baud rate: 57,600 bps  
                          | Operation data: UART serial communication. Baud rate: 128,000 bps |
| Supercapacitor Capacity| 4.2V 90F (6 x 15F, Vishay MAL219691253E3) |
Major Milestones of SPATIUM-I Mission

- Mission Mode Discussion and Definition: MDR: Nov 2016
- Start Date: Jul 2016
- PDR #1: Apr 2017
- CDR#1: Sep 2017
- PDR #2: May 2017
- CDR#2: Feb 2018
- Flight Model (FM)
- Engineering Model 2 (EM2)
- Engineering Model 1 (EM1)
- Bread Board Model (BBM)
- Launch to ISS 23rd Sep 2018
- Satellite Delivery 6th Aug 2018
- Release from ISS 6th Oct 2018
Preliminary Evaluation of CSAC in Actual Space Environment

- CubeSat released from ISS on 7th Oct 2018 at 15.45pm SGT (400km, 51.6 degree)
- First contact with SPATIUM CubeSat on 7th October 2018 at 20:14pm SGT (spread spectrum signal only)
- First demodulated data on 17th Oct 2018 at 08:17am SGT

- The accumulated CSAC counter value is 00000865F2660DAF (hex) or 9233951493551 (decimal), which is equivalent to 10 days 16 hours and 30 minutes.
- This duration is tallied with the total CubeSat operation period since its release from ISS. From the obtained satellite data, it can be assured that the SPATIUM CubeSat is working properly as per design.
Preliminary Evaluation of CSAC in Actual Space Environment

- SPATIUM-I met the primary objectives and demonstrated the key enabling technologies in orbit.
- The CubeSat is functioning since release from ISS till now (more than 9 months) and we are consistently downlink CubeSat data for analysis.

- No visible drift is observed in the count per second, indicating that the CSAC is working properly until now.
- Other satellite data showed that the critical parameters such as supercapacitor voltage level, CSAC temp, battery temp and COM temp are well-kept within very healthy range.
Conclusion

- SPATIUM program aims to provide a technology demonstration for development of a reliable ionospheric plasma density mapping platform with excellent spatial and temporal resolutions.

- The pathfinder SPATIUM-I aims to demonstrate a few enabling technologies for future mission. After 2 years efforts of design optimization and satellite testing, it was released from ISS on 6th Oct 2018.

- SPATIUM-I is the first nanosatellite in the world to successfully demonstrate a CSAC working in Low Earth Orbit. The satellite is working as per design until now (more than 9 months of operation).

- On-going efforts:
  - Data analysis and modelling of TEC.
  - SPATIUM-II - a CubeSat constellation mission for ionosphere plasma monitoring.
  - Exploration of other potential applications/missions
Thank You

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