NASA Update to WG-B

MMS GPS Performance at 29.34 Re (50% of way to the moon)

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NASA’s Magnetospheric MultiScale (MMS) Mission

• Discover the fundamental plasma physics process of reconnection in the Earth’s magnetosphere.

• Coordinated measurements from tetrahedral formation of four spacecraft in highly eccentric orbits with typical formation spacing of 20-40 km at apogee

• Flying two mission phases & 3 orbit scenarios
  – Phase 1: 1.2x12 $R_E$ (magnetopause), Mar ‘14-Feb ‘17
  – Phase 2B: 1.2x25 $R_E$ (magnetotail), May ‘17-Feb ‘19
  – Extended Mission: 1.2x29.34 $R_E$ (magnetotail), Higher apogee to reduce eclipse time, Feb ‘19-Present
Magnetospheric Multi-Scale (MMS)
- Launched March 12, 2015
- Four spacecraft form a tetrahedron near apogee for performing magnetospheric science measurements (space weather)
- Four spacecraft in highly eccentric orbits
  - Phase 1: 1.2 x 12 Earth Radii (Re) Orbit (7,600 km x 76,000 km)
  - Phase 2B: Extends apogee to 25 Re (~150,000 km)
  - Extended Mission: Feb ‘19 Apogee raising to 29.34 Re (50% of way to Moon!)

MMS Navigator System
- GPS enables onboard (autonomous) navigation and near autonomous station-keeping
- MMS Navigator system exceeds all expectations
- At the highest point of the MMS orbit Navigator set Guinness world record for the highest-ever reception of signals and onboard navigation solutions by an operational GPS receiver in space
- At the lowest point of the MMS orbit Navigator set Guinness world for fastest operational GPS receiver in space, at velocities over 35,000 km/h
MMS Navigator GPS Hardware

- GPS hardware all developed and tested at GSFC. Altogether, 8 electronics boxes, 8 USOs, 32 antennas and front ends.
- Tracking sensitivity down to ~22 dB·Hz.
Signal Tracking Performance: 29.34 Re
Signal Tracking Performance: 29.34 Re

Average 1 Signal in View at Apogee
Position Navigation Performance
12 Re, 25 Re, 29 Re

Root Variance: Radial, Lateral

Radial

Lateral
Point Solution Evolution
12 Re, 25 Re, 29 Re
Comparison of MMS 29.34 Re data with SSV Booklet Lunar Trajectory Analysis

**Booklet Lunar Trajectory Results**
- Signal availability drops out around 30 Re; Cause: signals drop below assumed 20 dBHz tracking threshold

**MMS 29.34 Re Results**
- Signal availability begins dropping near 29.34 RE; Cause: Tracking threshold of MMS system is around 20 dBHz
- Future missions could improve GNSS availability at 29 Re and at lunar distances by using higher gained antennas and/or more sensitive GNSS receivers
GPS Outage Results at 29.34 RE

MMS Orbit period ~ 3.5 days (~5040 min)
GPS mean outage per orbit: 345 min
Signal availability: ~93%
Conclusions

• In February 2019, MMS constellation raised to 29.34 Re apogee—approximately 50% of the way to the moon
• MMS continues to exhibit outstanding GPS performance throughout its orbit, despite nearing the tracking threshold of Navigator receiver/antenna system at apogee
• Data from MMS closely matches SSV Booklet signal loss around 30 Re as illustrated in the lunar trajectory analysis
• Higher gained antenna and/or more sensitive GNSS receivers can extend signal availability beyond 30 Re
• MMS mission provides solid data to enable the design of missions that can reliably use GNSS systems out to lunar distances