Architecture Study on Telemetry Coverage for Immediate Post-Separation Phase

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Outline of the Talk

- Introduction and Summary
- Network Coverage
- Transmitter/Transponder Options
- Preliminary Cost Driver List and Forward Plan
Introduction and Summary
Problem Statement

• Problem
  – Spacecraft that do not utilize SN usually lack telemetry coverage during launch vehicle separation phase
  – As a result, no RT data is transmitted to the Ground during mission critical events
  – In the event of a catastrophe, no flight telemetry is available for anomaly investigation

• JPL Design, Verification/Validation & Ops Principles for Flight Systems (Design Principles), Rev. 3
  – 3.1.2.1 Uplink/Downlink capabilities - The mission design shall provide for a real time downlink capability during mission critical events

• GSFC Rules for the Design, Development, Verification, and Operation of Flight Systems
  – 1.14 Mission Critical Telemetry and Command Capability - Continuous telemetry coverage shall be maintained during all mission-critical events. Mission-critical events shall be defined to include separation from the launch vehicle; power-up of major components or subsystems; deployment of mechanisms and/or mission-critical appendages; and all planned propulsive maneuvers required to establish mission orbit and/or achieve safe attitude. After separation from the launch vehicle, continuous command coverage shall be maintained during all following mission-critical events.
3.0 Mission Design

3.1 General

3.1.1 Launch Period - The launch period shall be of sufficient duration to provide a probability of successful launch equal to or greater than 99%. In the absence of sufficient launch vehicle history to justify a statistical analysis, a launch period of at least 20 days shall be chosen.

3.1.2 Communications during mission - critical events

*Note:* Mission-critical events are those that if not executed properly and in a timely manner could result in failure to achieve mission success, e.g., orbit insertion; entry, descent, and landing. A trajectory correction maneuver (TCM) is not mission-critical unless it must execute properly in the time scheduled for it, i.e., cannot be delayed.

*Note:* Protection against loss of unique data, e.g., one-time science is covered in 3.1.3.

3.1.2.1 Uplink/Downlink capabilities - The mission design shall provide for a real time downlink capability during mission critical events.

*Note:* Communications during other special mission events is addressed in 4.5.1.4.

3.1.2.2 Redundant data paths - Except for Earth orbiting missions, the mission design shall ensure that redundant data paths not vulnerable to potential single failure(s) exist for real time return of flight data from post-launch mission critical events.

*Note:* Scheduling of mission critical events to occur during the overlap of 2 tracking complexes is one way to satisfy this requirement.
Mission Critical Telemetry and Command Capability

Principle:
Continuous telemetry coverage shall be maintained during all mission-critical events. Mission-critical events shall be defined to include separation from the launch vehicle, power-up of major components or subsystems, deployment of mechanisms and/or mission-critical appendages, and all planned propulsive maneuvers required to establish mission orbit and/or achieve safe altitude. After separation from the launch vehicle, continuous command coverage shall be maintained during all following mission-critical events.

Rationale:
With continuous telemetry and command capability, operators can prevent anomalous events from propagating to mission loss. Also, flight data will be available for anomaly investigations.

Phase:

Activities:
1. Identify potential mission-critical events and concept of operations.
2. Identify critical components and concept of operations to ensure all potential needs for communications coverage, such as TDRSS or backup ground stations.
4. Address critical mission coverage requirements for ground system design.

Verification:
1. Verify at MCR.
2. Verify at PDR.
3. Verify at COR.
4. Verify at ORR.
5. Verify telemetry capability during mission operations.

Revision Status:
Revision C, October 30, 2008

Owner:
Guidance, Navigation and Control Systems Engineering (591)

Reference:
Check the GSFC Directives Management System at http://gdms.gsfc.nasa.gov for the latest version prior to use.
## Assumed LEOP Planetary Mission Set Baseline

(Based on 5/9/06 Agency Mission Planning Model)

<table>
<thead>
<tr>
<th>Year</th>
<th>Mission(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Phoenix, Dawn</td>
</tr>
<tr>
<td>2008</td>
<td>Kepler</td>
</tr>
<tr>
<td>2009</td>
<td>MSL</td>
</tr>
<tr>
<td>2010</td>
<td>Mars Scout 2, Juno</td>
</tr>
<tr>
<td>2011</td>
<td>Discovery 12</td>
</tr>
<tr>
<td>2012</td>
<td>Mars Science Orbiter, Discovery 13, MMS (4 S/C)</td>
</tr>
<tr>
<td>2013</td>
<td>Mars Scout 3, Terrestrial Planet Finder</td>
</tr>
<tr>
<td>2014</td>
<td>Discovery 16, New Frontiers 4</td>
</tr>
<tr>
<td>2015</td>
<td>Discovery 17, Beyond Einstein 2</td>
</tr>
<tr>
<td>2016</td>
<td>Discovery 18, New Frontiers 5, SEC ‘23</td>
</tr>
<tr>
<td>2017</td>
<td>Mars Scout 4</td>
</tr>
<tr>
<td>2018</td>
<td>Discovery 19, Large UV/IR, SEC ‘25</td>
</tr>
</tbody>
</table>

### Near-term Supports (15)

### Long-term Supports (19)
Summary of Preliminary Study

• Ground networks (including DSN) can only provide limited coverage at low altitude (< 10K km)
  – See DSN coverage example (next chart)
  – Require time-phase the spacecraft launch to ensure that the critical events occur when there is ground station coverage
    • Impose additional launch constraints
    • Might need to increase battery size
    • Small windows of opportunity for transmitting

• Space Network (SN) provides continuous and complete coverage for low altitude operation (< 10K km)
  – Existing COTS SN compatible transponders and transmitters are available for use in immediate post-separation communications
    • With low mass and power for small satellite applications
  – Imposes no launch constraints for coverage

• Further assessment needed to understand the end-to-end mission implementation impacts
Interpretation of Requirements and Proposed FOM

- Develop spacecraft telemetry recovery capability (2 kbps) to provide telemetry communication coverage immediately upon separation from the launch vehicle until solar panels and primary spacecraft telecom subsystem are activated
  - No uplink commanding and tracking
- Maximize network coverage
  - Consider existing and future space-based and ground-based networks that provide coverage during this phase
- Maximize spacecraft antenna coverage
  - Cover nominal and off-nominal spacecraft attitude (tumbling)
- Minimize additional mass* and volume* to spacecraft
- Minimize additional power* draw to spacecraft
  - Spacecraft runs on battery during this phase (solar panel not deployed)
- Minimize integration and testing cost*
  - Use standard interface to avionics
- Minimize development cost*
  - Consider COTS transponder or minor modification of existing transponder
  - Assume using Class C or D parts

* Proposed Figure of Merit
Network Coverage
Example of DSN Coverage

1,000 km (red)
5,000 km (yellow)
10,000 km (cyan)
20,000 km (green)
35,000 km (blue; ~Roughly Geo-sync)
40,000 km (magenta)
400,000 km (black; ~Average Moon distance)

Phoenix Launch
Separation at L+85 min
Return Telemetry at L+91 min

DSN Coverage of Phx at Different Altitudes (10° Mask)
GN Coverage (Goldstone Canberra Madrid)

DSS coverage
Exclusion zone

1000 km
5000 km
10,000 km

20,000 km
35,000 km

10° Elevation Mask

1,000 km (red); 5,000 km (yellow); 10,000 km (cyan); 20,000 km (green); 35,000 km (blue); 400,000 km (magenta); 400,000 km (black)

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Telemetry Coverage for Immediate Post-Separation Phase
DSN Coverage at Different Altitudes

1,000 km (red) 5,000 km (yellow) 10,000 km (cyan) 20,000 km (green) 35,000 km (blue) 40,000 km (magenta) 400,000 km (black)

Telemetry Coverage for Immediate Post-Separation Phase
# DSN Coverage @ Different Altitudes

<table>
<thead>
<tr>
<th>DSN Coverage @ Different Altitudes (Area %)</th>
<th>DSN3 (Gold, Canb, Madr)</th>
<th>DSN4 (Gold, Canb, Madr, Hart)</th>
<th>DSN5 (Gold, Canb, Madr, Hart, Sant)</th>
<th>DSN6 (Gold, Canb, Madr, Hart, Sant, Usuda)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000km</td>
<td>11</td>
<td>14</td>
<td>18</td>
<td>21</td>
</tr>
<tr>
<td>5,000km</td>
<td>46</td>
<td>59</td>
<td>73</td>
<td>86</td>
</tr>
<tr>
<td>10,000km</td>
<td>65</td>
<td>79</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>20,000km</td>
<td>77</td>
<td>90</td>
<td>95</td>
<td>100</td>
</tr>
<tr>
<td>35,000km</td>
<td>84</td>
<td>94</td>
<td>97</td>
<td>100</td>
</tr>
<tr>
<td>40,000km</td>
<td>85</td>
<td>95</td>
<td>98</td>
<td>100</td>
</tr>
<tr>
<td>400,000km</td>
<td>93</td>
<td>99</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
SN Coverage as Advertised in SNUG

- Space Network (from Space Network User’s Guide (SNUG) Rev 9)

**Figure 2-8. Example Average Line-of-Sight Coverage for SA EEFOV**

Note: The customer minimum altitude for 100% line-of-sight coverage is 73 km.
### SN Hemispheric Coverage

<table>
<thead>
<tr>
<th>SN Coverage</th>
<th>F3 &amp; F9 (same %)</th>
<th>F3 &amp; F9 (opposite %)</th>
<th>F3 &amp; F9 (total %)</th>
<th>F3 F8 &amp; F9 (same %)</th>
<th>F3 F8 &amp; F9 (opposite %)</th>
<th>F3 F8 &amp; F9 (total %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 km</td>
<td>90</td>
<td>10</td>
<td>100</td>
<td>99.6</td>
<td>0.4</td>
<td>100</td>
</tr>
<tr>
<td>5000 km</td>
<td>90</td>
<td>10</td>
<td>100</td>
<td>99.6</td>
<td>0.4</td>
<td>100</td>
</tr>
<tr>
<td>10000 km</td>
<td>87</td>
<td>12</td>
<td>99</td>
<td>99.5</td>
<td>0.5</td>
<td>100</td>
</tr>
<tr>
<td>20000 km</td>
<td>34</td>
<td>54</td>
<td>88</td>
<td>54.5</td>
<td>43.5</td>
<td>98</td>
</tr>
<tr>
<td>35000 km</td>
<td>10</td>
<td>51</td>
<td>61</td>
<td>18.5</td>
<td>62.5</td>
<td>81</td>
</tr>
</tbody>
</table>

Larger user’s power is needed (68,000 km to 83,000 km)

Extended Elliptical Field of View:
- F3: 22° East-West & 28° North-South from Nadir
- F8 & F9: 76.8° East-West & 30.5° North-South from Nadir
SN Coverage (F3 F8 & F9-TDRSS)

Same hemisphere coverage

Opposite hemisphere coverage

Exclusion zone

1,000 km (red); 5,000 km (yellow); 10,000 km (cyan); 20,000 km (green); 35,000 km (blue);

A Lot More of Opposite Hemisphere Coverage

62.5% opposite hemisphere coverage

Stationary Coverage for Immediate Post-Separation Phase

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• While SN can provide high surface area coverage percentage even at higher altitudes (20,000km & 35,000 km), most of the links occur when SN and the user are on the opposite hemispheres (slanted ranges ~ 68,000 km & 83,000 km, respectively).
• 10,000-plus-km altitude switch-over between SN & GN seems to be appropriate.
• Even though the GN covers 65% or more of the surface area at 10,000 km or higher altitudes, most of its coverage is centered around the equator, where majority of the missions stay.
• With the proposed 10,000-plus-km altitude switch-over, only F3 and F9 are needed.
Transmitter/Transponder Options
• **RF Approach Using TDRSS Network and TDRSS Compatible Transmitter (High TRL)**
  - Low Cost TDRSS Transmitter (Wallops)
  - T710 (L3 Communications)
  - T709 (L3 Communications)
  - T719 (L3 Communications)
  - EW C12 (Thales)
  - AeroAstro Transmitter (AeroAstro)
  - MST-765 (L3 Communications)

• **Other Possible Approaches**
  - RF Approach Using Upper Stage and Low Power/Mass Transmitter on spacecraft (Mid TRL)
  - Photonic Approach Using Upper Stage and Retro-Reflector (Low TRL)
  - SDST Modifications: Add a S-band slice on existing SDST
<table>
<thead>
<tr>
<th>SN Compatible Options</th>
<th>LCT2</th>
<th>T710/T710A/T710B</th>
<th>T709</th>
<th>T719</th>
<th>EW C12 0000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Wallops</td>
<td>L3</td>
<td>L3</td>
<td>L3</td>
<td>TES (Thales)</td>
</tr>
<tr>
<td>Transmitter Mass (Kg)</td>
<td>&lt; 0.9 Kg</td>
<td>&lt; 2.0 Kg</td>
<td>&lt; 4.7 Kg</td>
<td>&lt; 2.3 Kg</td>
<td>&lt; 0.5 Kg</td>
</tr>
<tr>
<td>Transceiver Mass (Kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmitter Dimensions (cm)</td>
<td>10.16 x 12.70 x 3.81</td>
<td>13.34 x 17.78 x 6.60</td>
<td>17.78 x 17.78 x 18.42</td>
<td>13.97 x 19.18 x 10.16 (from phone)</td>
<td>12.7 x 16.00 x 2.03</td>
</tr>
<tr>
<td># of antenna ports</td>
<td>2</td>
<td>2</td>
<td>1?</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Spacecraft Bus IF</td>
<td>RS232</td>
<td>RS422</td>
<td></td>
<td></td>
<td>RS422</td>
</tr>
<tr>
<td>Approximate Lead time</td>
<td>18 - 24 months.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parts and Grades</td>
<td>NASA B+</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Testing and Certification Process</td>
<td>Depends on acceptance test plan and part selection requirements.</td>
<td></td>
<td></td>
<td>Space Qualified</td>
<td></td>
</tr>
<tr>
<td>Previous Users</td>
<td>ELV Sounding Rocket</td>
<td>T710-ATLAS LV T710B CloudSat spacecraft T710A ATLAS-V LV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Notes</td>
<td>No radiation harden or tolerate.</td>
<td>Rugged Version of T710A, no digital processing slide for spread spectrum.</td>
<td>Very similar to T710, but with higher power output.</td>
<td>Digital dual mode</td>
<td></td>
</tr>
<tr>
<td>Tx/Rv Mode</td>
<td>Tx only. DG2</td>
<td>Tx only. DG2</td>
<td>Can support TDRSS MA when user provides PN spreading code.</td>
<td>DG1: mode2, DG1:mode3, DG2</td>
<td>QPSK, Rate 1/2 coding</td>
</tr>
<tr>
<td>Oscillator</td>
<td>TCXO reference</td>
<td>TCXO reference</td>
<td>OCXO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>2200 - 2300</td>
<td>2200 - 2300</td>
<td>2200-2300</td>
<td>2200-2300</td>
<td>2200-2290</td>
</tr>
<tr>
<td>RF Power Output</td>
<td>10W (20W in development)</td>
<td>3W min. (total), 1.5W min (each)</td>
<td>26 W</td>
<td>7 W</td>
<td>2 W (5W option Available)</td>
</tr>
<tr>
<td>DC Power Input</td>
<td>&lt; 69W</td>
<td>&lt; 35W</td>
<td>145 W</td>
<td>37 W</td>
<td>10 W, 2.5 W standby</td>
</tr>
</tbody>
</table>

5/12/08 Telemetry Coverage for Immediate Post-Separation Phase
### Preliminary Flight System Findings (2)

Non-spread, residual carrier PCM/PSK/PM and PCM/PSK/PM signal designs can be used for short duration with prior coordination with GSFC Space Communications Program/Code 450.

#### SN Compatible Options, GN Mode Only

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>AeroAstro</th>
<th>SDST Modifications</th>
<th>MST-765</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter Mass (Kg)</td>
<td>0.6 Kg</td>
<td>0.72 Kg increase</td>
<td>0.80 Kg</td>
</tr>
<tr>
<td>Transceiver Mass (Kg)</td>
<td>0.9 Kg</td>
<td>0.72 Kg increase</td>
<td>1.60 Kg</td>
</tr>
<tr>
<td>Transmitter Dimensions (cm)</td>
<td>8.89 x 5.08 x 2.79</td>
<td>52.26 cm² increase in footprint</td>
<td>15.24 x 12.7 x 3.81</td>
</tr>
<tr>
<td># of antenna ports</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Spacecraft Bus IF</td>
<td>RS422</td>
<td>Same as SDST</td>
<td>RS-422</td>
</tr>
<tr>
<td>Approximate Lead time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parts and Grades</td>
<td></td>
<td>Same as SDST</td>
<td></td>
</tr>
<tr>
<td>Testing and Certification Process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approximate Cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous Users</td>
<td>MOST Mission, Canada</td>
<td>Heritage from SDST</td>
<td>ROCSAT III</td>
</tr>
<tr>
<td>Other Notes</td>
<td>10 kRads (Si)</td>
<td>Same as SDST</td>
<td>100 kRads</td>
</tr>
<tr>
<td>Tx/Rv Mode</td>
<td>Tx only. PCM/PSK/PM PCM/PM (DG2?)</td>
<td>Tx only. PCM/PSK/PM PCM/PM (DG2?)</td>
<td></td>
</tr>
<tr>
<td>Oscillator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>2200 - 2300</td>
<td>2200 - 2300</td>
<td>2200-2300</td>
</tr>
<tr>
<td>RF Power Output</td>
<td>5W</td>
<td>5W</td>
<td>5W (6.5W available)</td>
</tr>
<tr>
<td>DC Power Input</td>
<td>~32W</td>
<td>26.3W</td>
<td>35W</td>
</tr>
</tbody>
</table>

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Telemetry Coverage for Immediate Post-Separation Phase
Example of AeroAstro Transceiver

Capabilities
- SGLS, STDN and TDRS variants
- Interface for MCU-110 crypto unit
- SPA-U, RS-422, RS-485 & custom I/F
- PRN ranging / coherency supported
- Uplink at 1, 2 or 10kbps
- Downlink at rates up to 25 Mbps

Characteristics
- 1-4 modules; each 3.5 x 2 x 1 inches (RX,TX,HPA & interface/power)
- Mass: <200g per module
- Receiver power: <1 Watt
- Transmit (0.5Wrf): <8 Watts
- Transmit (5.0Wrf): <32 Watts
- Primary/secondary isolation: >1MΩ
Example of Thales Transceiver

<table>
<thead>
<tr>
<th>LINK BUDGET - SSA Return</th>
<th>TDRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Band</td>
<td>S</td>
</tr>
<tr>
<td>FEC Coding</td>
<td>Rate 1/2</td>
</tr>
<tr>
<td>Xmitter power watts</td>
<td>watts 2.00</td>
</tr>
<tr>
<td>Xmitter power dBW</td>
<td>3.0</td>
</tr>
<tr>
<td>Frequency MHz</td>
<td>2287.0</td>
</tr>
<tr>
<td>Transmit antenna gain dB</td>
<td>0.0</td>
</tr>
<tr>
<td>Polarization</td>
<td>CP/LP cp</td>
</tr>
<tr>
<td>Circuit Loss</td>
<td>-3.0</td>
</tr>
<tr>
<td>Antenna Pointing Loss dB</td>
<td>0.0</td>
</tr>
<tr>
<td>EIRP dBm</td>
<td>0.0</td>
</tr>
<tr>
<td>Range km</td>
<td>44000.0</td>
</tr>
<tr>
<td>Free space loss dB</td>
<td>-192.5</td>
</tr>
<tr>
<td>Atmospheric attenuation dB</td>
<td>0.0</td>
</tr>
<tr>
<td>Receive antenna gain dB</td>
<td>37.0</td>
</tr>
<tr>
<td>Receive Antenna Polarization cp</td>
<td></td>
</tr>
<tr>
<td>Receive Antenna Polarization Loss dB</td>
<td>0.0</td>
</tr>
<tr>
<td>Antenna Pointing Loss dB</td>
<td>0.0</td>
</tr>
<tr>
<td>Circuit Loss dB</td>
<td>-1.0</td>
</tr>
<tr>
<td>Received Signal Power dBW</td>
<td>-156.4</td>
</tr>
<tr>
<td>Receiver NF dB</td>
<td>3.5</td>
</tr>
<tr>
<td>Tsky K</td>
<td>20.0</td>
</tr>
<tr>
<td>Tsys dB K</td>
<td>434.8</td>
</tr>
<tr>
<td>Tsys dB/K</td>
<td>26.4</td>
</tr>
<tr>
<td>Receive G/T dB/K</td>
<td>10.6</td>
</tr>
<tr>
<td>No dBw/Hz</td>
<td>-202.2</td>
</tr>
<tr>
<td>Pt/No dBHz</td>
<td>45.8</td>
</tr>
<tr>
<td>Data Rate kbps</td>
<td>2</td>
</tr>
<tr>
<td>DATA RATE dB</td>
<td>33.0</td>
</tr>
<tr>
<td>Eb/No Available dB</td>
<td>12.8</td>
</tr>
<tr>
<td>Eb/No Required dB</td>
<td>4.5</td>
</tr>
<tr>
<td>Receive System Impl Loss dB</td>
<td>3.0</td>
</tr>
<tr>
<td>LINK MARGIN dB</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Space Flight Qualified S band Transceiver in three Modules:
Transmitter + Receiver + Diplexer = 1150 grams

Transmitter Module:
• 2 Watts RF, 8 W DC
• Data Rate as low as 2 kbps
• Weight < 500 grams

5/12/08 Telemetry Coverage for Immediate Post-Separation Phase
Preliminary Cost Driver List and Forward Plan
Mission Cost Elements

1. **Telecom Hardware**
   - Radio, antenna, coaxial cables, switches, etc.

2. **Flight System Accommodation**
   - Power, thermal, C&DH, field of view, cable routing, switching, S/W
   - Logics for fault-tolerant
   - May require new reviews, decision gates, and testing/verification processes in development and operation phases

3. **ATLO/Test Cost**
   - EMC/EMI
   - Compatibility
   - Qualification

4. **MOS/GDS Cost**

5. **Network Cost**

Cost impacts to be evaluated in next step
Study Plan (1)

- SN network coverage analysis and detailed SN coverage requirements (Completed)
- Summary of prior studies
- Feasibility study on spacecraft separation at TBD km or higher
  - If feasible, kickoff architecture study of ground asset option
  - 1000 km is feasible in recent missions (Phoenix and DAWN)
- Analyze nominal and off-nominal (3 \( \sigma \) dispersion) vehicle separation scenarios
  - Obtain representative spacecraft launch trajectory and altitude profiles
  - Derive range, range rate, and compile Doppler, Doppler rate statistics
  - Compile detailed launch vehicle separation sequence of events
  - Estimate spacecraft critical telemetry generation rates
- Analyze spacecraft antenna coverage and derive spacecraft coverage requirements
- Develop communication performance requirements
- Re-assess and update the list SN transmitter options, and assess the SN return link performance
  - Mass, DC power, output power, cost, etc.
  - Take into account communication performance requirements in dynamic environment
Study Plan (2)

- **Spacecraft accommodation**
  - Total additional mass, integration cost, additional telemetry channels, etc.
  - Will this post-separation communication be part of the go-no-go decision of launch?
  - Identify decision points in mission planning life cycle as on whether post-separation transmitter is needed or not

- **ATLO/testing**
  - Testing process, cost

- **MOS/GDS Setup**
  - Operation development, training, and cost

- **SN coordination**
  - Coordination for launch support, interface to mission MOS/GDS, cost

- **Identify other space-based and ground-based improvements and forward works**