Transformational Satellite Communications System (TSAT) Description

- Transforms satellite communications (SATCOM)
  - Extends DoD ground-based Global Information Grid (GIG) network to deployed and mobile users
    - Implements worldwide networking based on Internet Protocol
    - Laser communications (huge capacity gains)
- Enables service warfighting visions:
  - Mobile battle command on the move
    - Current systems force comm-on-the-pause, or -stop
  - Shared situational awareness
    - Red/blue force tracking; real-time intel
    - Complete sensor-to-shooter (through C2) capability
  - Collaborative, offensive-oriented planning
    - Enables dynamic/high-tempo operations
  - Provides assured command & control to strategic forces
  - Linchpin for 21st century net-centric warfare
    - Communicate as a joint networked force
Continuous Capacity and Protection Improvements: Being Responsive to our Warfighter Needs
<table>
<thead>
<tr>
<th>Time Period</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid ’70s</td>
<td>LES 8/9</td>
</tr>
<tr>
<td></td>
<td>First space-based spread spectrum and communication processing</td>
</tr>
<tr>
<td></td>
<td>Single channel</td>
</tr>
<tr>
<td>Mid-Late ’80s</td>
<td>Milstar I</td>
</tr>
<tr>
<td></td>
<td>First strategic / tactical operational EHF spacecraft</td>
</tr>
<tr>
<td></td>
<td>LDR only</td>
</tr>
<tr>
<td></td>
<td>Electronically agile beams</td>
</tr>
<tr>
<td>Early ’90s</td>
<td>Milstar II</td>
</tr>
<tr>
<td></td>
<td>10x capacity increase (MDR)</td>
</tr>
<tr>
<td></td>
<td>Nulling antenna</td>
</tr>
<tr>
<td>Late ’90s</td>
<td>AEHF</td>
</tr>
<tr>
<td></td>
<td>10x increase in capacity (XDR)</td>
</tr>
<tr>
<td></td>
<td>Increased accesses for small terminals</td>
</tr>
<tr>
<td></td>
<td>First protected bandwidth-efficient waveform (binary only)</td>
</tr>
<tr>
<td></td>
<td>Remains circuit-based DAMA</td>
</tr>
<tr>
<td>2005</td>
<td>TSAT</td>
</tr>
<tr>
<td></td>
<td>10x increase in RF capacity (XDR+)</td>
</tr>
<tr>
<td></td>
<td>Increased bandwidth efficiency (up to 16-ary)</td>
</tr>
<tr>
<td></td>
<td>IP routing</td>
</tr>
<tr>
<td></td>
<td>Dynamic packet-based resource allocation</td>
</tr>
<tr>
<td></td>
<td>High-gain theater coverage (COTM)</td>
</tr>
</tbody>
</table>

3 orders of magnitude capacity increase
TSAT Critical Technologies

- Battle Command On the Move (BCOTM)
- Next Generation Processor/Router
- Bandwidth Efficient Modulation
- Dynamic Bandwidth Resource Allocation
- Transec
- Space HAIPE
- Lasercom

- Tactical
- STRAT

16 independent uplink cover keys per satellite
Two independent uplink patterns per satellite

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17 April 2007
TSAT Definition of Technology Maturity/Readiness

Heritage + Flight Experiments = Tech Readiness

Breadboard Demos + Independent Validation + Parts Pre-Qualification + Independent Validation + Brassboard Demos

Multiple activities used to establish tech readiness
**TSAT Technology Readiness Level (TRL)**

![Diagram showing technology readiness levels for various technologies over fiscal years. Key technologies include NGPR, Lasercom, Battle Command on-the-move (BCOTM) Antenna, and more.]

**Key technologies will be demonstrated to TRL-6 by KDP-B**

**HAIPE:** High Assurance Internet Protocol Encryption

**ISDDR:** Interim Space Segment Design Review

**OSVS:** Optical Standards Validation Suite

**NGPR:** Next Generation Processor Router

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**Test Events**

- **Test Event I** (Nov 2005 – Mar 2006) - **Breadboard**
  - Lasercom (LCT-1)
    - Waveform compatibility/perf at 10/40 Gbps
    - PAT (pointing, acquisition, tracking)
  - NGPR (NGPR-1)
    - XDR+ waveform interoperability
    - Signal timing/tracking, data framing

- **Test Event II** (Nov 2006 – Feb 2007) - **Brassboard**
  - Lasercom (LCT-2)
    - Signaling interoperability/perf at 2.5/10/40 Gbps
  - NGPR (NGPR-2)
    - Integration of advanced signaling (XDR+) with IPv6 networking and DBRA

**Completed**
Maturation Example: Lasercom

Heritage

LITE-2 EM (Fiber-Based) 1990's

Introduction of commercial parts
• Leverage large-scale manufacturing processes

Flight Experiments

Lasercom Experiment (GeoLITE, 2001)

Airborne Laser Experiment Alex Demonstration (2002)

Breadboard

Parts Prequal

Key components/subassemblies
• Optical fiber
• Optical & RF Filters
• Optical & RF Modulators/Demodulators
• Diode transmitters/receivers
• Optical switches
• Interferometers
• Couplers/isolators

Vendor development and major Environment Testing (examples)
• Failure modes and Effects Analysis (FMEA)
• Thermal temperature cycling
• Vacuum
• Vibration
• Mechanical Shock
• Total Dose
• Prompt Dose /SEU

Brassboard

Pre 2000 2001/2 2005 2006 2007
Independent Validation

- Independent test assets
  - Network, RF, Optical, and High-Speed Electronics Test Systems
  - Operate stand-alone or as part of integrated infrastructure

- Government test team

- Government assessment of functionality/performance

Independent test capability for Government technology performance assessment
Next Steps in Technology Maturation

Technology Integration

<table>
<thead>
<tr>
<th>RRSD Phase</th>
<th>Post SS ATP Test Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY06</td>
<td>FY07</td>
</tr>
<tr>
<td>NFGR-1</td>
<td>NFGR-2</td>
</tr>
<tr>
<td>BEM</td>
<td>BEM</td>
</tr>
<tr>
<td></td>
<td>DBRA</td>
</tr>
<tr>
<td></td>
<td>HAIPE</td>
</tr>
<tr>
<td>Basic Network Protocols</td>
<td></td>
</tr>
<tr>
<td>SA Lasercom Breadboard</td>
<td>SA Lasercom Brassboard</td>
</tr>
<tr>
<td>OSVS-1</td>
<td>OSVS-2</td>
</tr>
<tr>
<td>SONET</td>
<td>SONET</td>
</tr>
</tbody>
</table>

System Integration

Engineering Model Qualification
Hardware & Software Integration and Test

Flight BCOTM Antenna
Flight NGPR SONET
Flight SA LC

Higher risk integration prior to SS ATP, lower risk afterward
Back Up
Summary

• MILSATCOM history
  • Continual expansion by leveraging the latest technology

• Space systems development
  • Need to balance technology risk versus performance
  • Disciplined technology maturation is essential

• Transformational communications success hinges on successful technology maturation
  • Technology demonstration on track to TRL-6
  • More maturity and integration planned for the future
**TSAT System**

**Space Segment**
Five satellite constellation crosslinked via lasercom

**Terminal Segment**
- Radio Frequency Users
  - Strategic forces
  - Ground, air, and sea tactical forces
  - Airborne intelligence, surveillance, and reconnaissance assets

**Mission Operations Segment**
TSAT Mission Operations System (TMOS)

**Intelligence, surveillance, and reconnaissance (ISR) assets**

- Lasercom Users

- Satellite operations control

- Gateways

Links to DoD, and intelligence community

Global Information Grid (GIG) infrastructure

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LCT-2 Free Space Communications Testing
Complete: Feb 07

OSVS Terminal Simulator
OSVS Channel Simulator
TSAT Contractor
Terminal Under Test

2.5/10/40 Gbps Source / Sink
OSVS Terminal Simulator
OSVS Channel Simulator
TSAT Contractor
Terminal Under Test

86,000 Km

Independent testing of LM-NGST and BSS terminals accomplished on schedule
NGPR-2 Bandwidth Efficient Modulation (BEM) Testing Complete: Feb 07

- Four new TSAT modulation / coding pairs for XDR+ provide more throughput in fixed bandwidth
  - Enable power efficiency and interference protection
  - Allow multiple users to share a single band

Testing Network communications with TSAT XDR+
uplink/downlink waveform
### WGS vs. AEHF vs. TSAT

<table>
<thead>
<tr>
<th></th>
<th>WGS Per Satellite</th>
<th>AEHF Per Satellite</th>
<th>TSAT Per Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BCOTM</strong>*</td>
<td>-</td>
<td>COTP--140 links @ 32 Kbps↑ 256 Kbps↓</td>
<td>300 links*** @ 1544 Kbps</td>
</tr>
<tr>
<td>1’ Antenna</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td><strong>AISR</strong></td>
<td>2 links @ 274 Mbps</td>
<td>--</td>
<td>6 links @ 311 Mbps</td>
</tr>
<tr>
<td>High Resolution</td>
<td></td>
<td>--</td>
<td></td>
</tr>
<tr>
<td><strong>AISR</strong></td>
<td>--</td>
<td>--</td>
<td>6 links@2448 Mbps**</td>
</tr>
<tr>
<td>Hyperspectral</td>
<td></td>
<td>--</td>
<td></td>
</tr>
<tr>
<td><strong>Space Based</strong></td>
<td>--</td>
<td>--</td>
<td>Up to 10 Gbps</td>
</tr>
<tr>
<td><strong>ISR</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Connectivity</strong></td>
<td>Pt to Pt to multipoint</td>
<td>Pt to Pt to multipoint</td>
<td>Full mesh—everyone</td>
</tr>
<tr>
<td><strong>Strategic</strong></td>
<td>--</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Battle Command on-the-Move (BCOTM) includes network core services, such as Voice, VTC, Broadcast Imagery, Web-based Traffic
* Overall constellation available laser links

*** TSAT router enables BCOTM urban operations
Protected Bandwidth Efficient Modulation (PBEM)

- Four new TSAT (XDR+) modulation / coding pairs provide more throughput in fixed bandwidth

![Graph showing Bandwidth Efficiency (BE) vs. Bit Signal-to-Noise Ratio, E_b/N_o (dB)]

- Capacity, C (bits/sec/Hz)
- Shannon Limit
- 12-4-QAM
- 8-PSK
- QPSK
- BPSK

Iterative Decoding and Interleaving

Enable power efficiency and interference protection

Decoder 1

\( \Pi^{-1} \)

\( \Pi \)

Decoder 2

Timing and Hop Framing

Allow multiple users to share a single band

- Comm accesses
- Time probe accesses
OSVS Test Result Example
Data Shown Taken on LL Terminal

WFS Data Yielding Radiant Intensity

Near field beam:
Diameter = 153.8mm
Rms wfe (tilt removed) = 0.053λ rms
Note: 12-inch relay used

Narrow Beam of Source

FWHM = 11.33 μrad
1/e2 radius = 9.30 μrad
TUT Mirror Commanded

OSVS Observed

Ability to measure μrad scans demonstrated
## TSAT Space and Terminal Synchronization

### Terminal Fielding Based on Services POM08 Plans (Fall 2006)

- Terminal fielding numbers represent the cumulative number of terminals from all Services
- At TSAT IOC in FY17, 742 AEHF terminals and 1152 TSAT terminals fielded
  - Issues: HC3 COTM not synchronized with TSAT, no plans for Airborne Lasercom Terminal

### Table: TSAT Fielding by Year

<table>
<thead>
<tr>
<th>Year</th>
<th>Legacy AEHF Terminals</th>
<th>TSAT Terminals (XDR+ and/or Ka Proc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY12</td>
<td>562</td>
<td>129</td>
</tr>
<tr>
<td>FY13</td>
<td>666</td>
<td>448</td>
</tr>
<tr>
<td>FY14</td>
<td>762</td>
<td>756</td>
</tr>
<tr>
<td>FY15</td>
<td>731</td>
<td>1152</td>
</tr>
<tr>
<td>FY16</td>
<td>742</td>
<td>1375</td>
</tr>
<tr>
<td>FY17</td>
<td>742</td>
<td>1678</td>
</tr>
<tr>
<td>FY18</td>
<td>737</td>
<td>2129</td>
</tr>
<tr>
<td>FY19</td>
<td>683</td>
<td>2964</td>
</tr>
<tr>
<td>FY20</td>
<td>658</td>
<td>3733</td>
</tr>
<tr>
<td>FY21</td>
<td>606</td>
<td>4385</td>
</tr>
<tr>
<td>FY22</td>
<td>563</td>
<td>4728</td>
</tr>
<tr>
<td>FY23</td>
<td>533</td>
<td>5017</td>
</tr>
<tr>
<td>FY24</td>
<td>529</td>
<td></td>
</tr>
<tr>
<td>FY25</td>
<td>529</td>
<td></td>
</tr>
</tbody>
</table>

### Diagram: Space Segment and Terminal Segment

- Pre-IOC: 0% - 19%
- IOC: 20% - 64%
- FOC: 65% - 100%

- Launch indicator: ★

Data Call: Current as of: POM08 3/7/2007

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