Switched Array Antenna System for SATCOM on the Move (SOTM)

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The Problem

• USMC Requirement to communicate on the move
  – In weather
  – Long haul

• Objective for Office of Naval Research (ONR):
  – Develop with industry a satellite terminal for military vehicles sending/receiving 256kbps or more
  – System should be relatively affordable, easily maintained
Program Overview

• Phase I system study (ONR FNC Program)
  – Trade study on potential satellite systems: commercial (C, Ku-band) and military (X-, Ka-band)
  – X-Band WGS selected as the most cost effective solution
• Phase II prototype I design (ONR FNC Program)
  – Design and fabrication of prototype subsystem components
  – Demonstrated a hybrid aperture solution – Phased array on gimbal
• Phase II prototype II design (ONR FNC Program)
  – 5-Faced phased array solution
    – No moving parts: reduces failure rate
  – TRL 6 hardware completed
• Phase III demonstration (Following transition to USMC in FY 2012)
  – Demonstration of SATCOM terminal for current program capabilities
Phase I Study: WGS X-Band Selected

• System selection factors
  – Ku-Band
    • Linear Polarization complicates performance and isolation, requires significantly more RF electronics, thus driving cost, size
    • Limited amount of bandwidth available in many parts of the world (e.g., CENTCOM) given current terminals utilizing commercial bandwidth
  – K/Ka-Band
    • Link weather effects are significant (i.e., Rain)
      – Drives aperture size higher to obtain higher EIRP and G/T
      – Requires more power – more demands on active cooling system
      – May never be able to meet 97% availability
    • System maturity lags X-Band by 24 to 36 months
  – X-Band
    • Link weather effects manageable
    • Component technology cost competitive and ready for prototyping
    • Access to both Government owned and Commercial Satellite systems
    • Equivalent physical size X-Band vs. Ka-Band array
      – Ka provides 60% of the data rate on receive and 50% on transmit
      – Ka has 15x DC power draw increasing thermal dissipation

X-Band Provides the lowest cost per Megabit
## System Requirements

<table>
<thead>
<tr>
<th></th>
<th>(X-band)</th>
<th>(Ku-band)</th>
<th>(Ka-band)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>MMLCA</td>
<td>Cobra-3/4180-LC</td>
<td>Cobra-3/4160-LC</td>
</tr>
<tr>
<td><strong>Data Rate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>uplink</td>
<td>256 kbps</td>
<td></td>
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<tr>
<td>downlink</td>
<td>512 kbps</td>
<td></td>
<td></td>
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<tr>
<td><strong>Availability</strong></td>
<td>97%</td>
<td></td>
<td></td>
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<tr>
<td><strong>Rain attenuation @ 4 mm/hr</strong></td>
<td></td>
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<tr>
<td>OTM performance</td>
<td>Churchville-B/ Perryman-3</td>
<td>MIL-STD-810F</td>
<td>MIL-STD-810F</td>
</tr>
<tr>
<td><strong>Scanning</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Azimuth</td>
<td>0° to 360°</td>
<td>0° to 360°</td>
<td>0° to 360°</td>
</tr>
<tr>
<td>Elevation</td>
<td>10° to 90°</td>
<td>0° to 90°</td>
<td>0° to 90°</td>
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<tr>
<td><strong>SWaP</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aperture size</td>
<td>8&quot; (H) X 16&quot;</td>
<td>18&quot;</td>
<td>16&quot;</td>
</tr>
<tr>
<td>Dimensions</td>
<td>32&quot; x 32&quot; x 9.5&quot;</td>
<td>26&quot; x 26&quot; x 23&quot;(H)</td>
<td>26&quot; x 26&quot; x 17.5&quot;(H)</td>
</tr>
<tr>
<td>Weight</td>
<td>&lt; 100 lbs</td>
<td>&lt; 120 lbs</td>
<td>&lt; 105 lbs</td>
</tr>
<tr>
<td>Power Draw</td>
<td>&lt; 500W</td>
<td>peak 750W, 450W continuous</td>
<td>peak 700W, 400W continuous</td>
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<tr>
<td>AHRS</td>
<td>internal</td>
<td></td>
<td></td>
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<tr>
<td>Cost (per qty)</td>
<td>$75K/unit in qty of 700</td>
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</table>
Prototype Terminal

• RF Parameters
  – G/T: 3.62 dB/K (0.21 dB/K at worst case scan angle)
  – EIRP: 34.12 dBW (29.7 dBW at worst case scan angle)
  – Full Duplex
  – 8 x 16 element receive array
  – 8 x 8 transmit array

• Data Rate
  – based on WGS EOL specification:
    • 512 kbps downlink
    • 256 kbps uplink
  – based on WGS predicted EOL (based on degraded BOL measured data)
    • Up to 2.0 Mbps downlink
    • Up to 1.5 Mbps uplink
Designed for Supportability

- Maintenance concept: MMLCA is line replaceable unit (LRU)
  - Remove/replace LRU at organizational level, return to depot for repair
    - Non-complex LRU replacement task
      - Requires standard tools only; no special support equipment or realignment/calibration required
      - 2 person task (~90 lbs), minimal training requirements, low MTTR
    - System health monitoring promotes health assessment: air pressure, humidity, temperature, operating time meter
      - Dedicated test connector provided for LRU fault detection/fault isolation
  - Potential LRU scheduled maintenance tasks at forward (non-depot) facility
    - Desiccant replacement
    - Cooler servicing
    - Periodic system inspection and check out
  - Planned maintenance enhancements
    - Built-in Test (BIT) self-diagnostics as needed to support maintenance concept
    - TBD, pending user/customer input
WGS Coverage Analysis vs. Rain Region (Crane Model) Analyzed

Red Contour: 10° El Look Angle

Yellow Contour: 50° El Look Angle

Green Contour: 80° El Look Angle
Link Margin over 10 elevation angle (Rain Region C) for all elevation angles

Analysis Assumes Worst Case Conditions
UNCLASSIFIED
Prototype II Acceptance Testing

CERDEC/Aberdeen Proving Ground - February 27 to March 9, 2012

• Tests were conducted within CERDEC SOTM lab parking lot and on Perryman 3 off-road course

• Tests conducted over XTAR-LANT with CERDEC X-band hub (on-site)
  – At-the-Hault (ATH)
    • Single face Eb/No – in/outbound
    • Hard handoff
    • Bit Error Rate (BER)
  – On-the-move (OTM)
    • Hard handoff
    • Soft receive handoff
    • Bit Error Rate (BER) in both directions
    • Beacon tracking

– Full duplex video/audio (VOIP) links
  • Parking Lot – low speed, high speed, “S” turns, Circles etc.
  • Off Road Course – Perryman 3 low speed
  • Off Road Course – Perryman 3 full speed (20mph, course MAX speed)
Face Handoff Link Disruption

- As vehicle turns, face with the best view of satellite is used.
- RF switching between array faces induces a phase change.
- The modem cannot maintain synchronization resulting in a short duration of increase bit errors, resulting in brief glitches in transmission & reception.
Test Setup

- 2.4m dish
- PA output Power: +29dBm
- Loss after PA: ~3dB
- Gain Estimate: 44.5dB
- G/T Estimate: 22 dB/K
- EIRP Estimate: 69-70.5dBm

- MMLCA antenna mounted on HMMWV
- Talin INS used for all tests
- Mounting location of the TALIN INS and GPS antenna caused minimal blockage on face 3 (rear face)
Results

• Successful operation for both testing and for demonstrations for ONR, CERDEC, MARCORSYSCOM and HQ MC as well as SOCOM in April 2012

• Minimal interruption for video, none detected for audio
  – Immediate recovery, minimal tiling
  – Also worked during mist and light rain
Program Going Forward

• Picked up by Marine Corps for transition development (MARCORSYSCOM)
  – Improvements to cooling system
  – Lightening of structure to meet < 100 lbs requirement

• Adherence to emerging standards for mobile SATCOM
  – Previous DoD standards assumed stationary parabolics only for satellite communications
  – Emerging standards for phased array and for mobile performance requirements
Self Contained Cooling System

• Integrated, closed system
• System cooling requirement
  • Antenna heatsink 35°C
  • Ambient 60°C
  • 330 dissipated watts
    • 100 watts – Electronics
    • 25 watts – Rx (2X)
    • 90 watts – Tx (2X)
• Active cooling approach supplied by Aspen Systems
  • 2 Stage Vapor Compression
  • Active Cooling System
• Integrated Evaporator/Coldplate

Cooling system is 64% of total projected production weight
Advantages of Electronically Steered X-Band Phased-Array

• No rotating components
  – Higher reliability
  – Fewer data dropouts – no keyhole
• Atmospheric losses at X-Band lower than at Ku and Ka-Bands
  – Less signal attenuation over distance
  – Less signal attenuation due to atmospheric moisture
    • X Band requires less link margin than Ku and Ka Bands
    • X-Band provides equivalent performance with lower EIRP and G/T
• Compared to Ka, X-Band provides 66% greater data rate in receive mode and 100% greater data rate in transmit mode
• Compared to Ka, X-Band requires only 1/15th the power for data transfer and cooling
• Both military and commercial satellites are available in X-Band
  – Ku-Band satellites commercial only
  – Ka-Band primarily military