Cutting Edge RFID Technologies for NASA Applications

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Outline

• Inventory management in space
  – Apollo, Space Shuttle, Space Station

• Potential RFID uses in a remote human outpost

• Ultra-Wideband RFID for Tracking

• Passive, wireless sensors in NASA applications
  – Micrometeoroid impact detection
  – Sensor measurements in environmental facilities

• E-textiles for wireless and RFID
Apollo Inventory Concept

Top level stowage drawing showing Command Module stowage layout

Sample table of items contained in modular container locations – used to layout vehicle and train crews on item locations

(Reference Apollo Experience Report: Crew Station Integration - Stowage & the Support Team Concept, 1972)

<table>
<thead>
<tr>
<th>Stowage location (a)</th>
<th>Equipment</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A5</td>
<td>Headrest pads</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Heel restraints</td>
<td>3 pair</td>
</tr>
<tr>
<td></td>
<td>Sleep restraint ropes</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Sextant adapter for 16-mm camera</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Spotmeter</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Two-speed timer</td>
<td>1</td>
</tr>
<tr>
<td>A6</td>
<td>Carbon dioxide absorbers</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Television monitor with cable and strap</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>12-foot television cable with strap</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Television-camera bracket</td>
<td>1</td>
</tr>
</tbody>
</table>
Shuttle Inventory Concept (non-Transfer to ISS)

- Crew is provided hard copy of items listed by location (no part numbers, serial numbers, etc., provided)
- Crew also has the ability to look items up in laptop database, but often requests item locations from Mission Control

STSW-109 MIDDECK STOWAGE

**FORWARD LOCKERS**

<table>
<thead>
<tr>
<th>MF14E</th>
<th>Food, Menu</th>
</tr>
</thead>
<tbody>
<tr>
<td>MF14G</td>
<td>Clothing, CDR</td>
</tr>
<tr>
<td>MF14H</td>
<td>Clothing, CDR</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MF14H (Cont)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kits</td>
</tr>
<tr>
<td>Comm</td>
</tr>
<tr>
<td>Cables</td>
</tr>
<tr>
<td>Comm, 4 ft</td>
</tr>
<tr>
<td>Comm, 14 ft</td>
</tr>
<tr>
<td>Mic, Handheld (3)</td>
</tr>
<tr>
<td>V/HS (2)</td>
</tr>
<tr>
<td>Saliva</td>
</tr>
<tr>
<td>Mirror (2)</td>
</tr>
<tr>
<td>O2 Bleed Orifice</td>
</tr>
<tr>
<td>Pip Pin (12)</td>
</tr>
<tr>
<td>Pip Pin, Escape Pole (Spare)</td>
</tr>
<tr>
<td>Switch Guard, Computer</td>
</tr>
<tr>
<td>Tape</td>
</tr>
<tr>
<td>Gray, 1 in</td>
</tr>
<tr>
<td>Gray, 2 in</td>
</tr>
<tr>
<td>Ziploc, 8 in (20)</td>
</tr>
<tr>
<td>Ziploc, 12 in (9)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MF14K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Bottles</td>
</tr>
<tr>
<td>Breaker Bar, 3/8 in</td>
</tr>
<tr>
<td>Breakout Box</td>
</tr>
<tr>
<td>Filter, Waste Water Dump Kit, RMS D&amp;C</td>
</tr>
<tr>
<td>Turnbuckles</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MF14M</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDF</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MF14O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food, Menu</td>
</tr>
<tr>
<td>Food, Menu</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MF28E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food, Menu</td>
</tr>
<tr>
<td>Food, Menu</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MF28G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clothing, PLT</td>
</tr>
<tr>
<td>Clothing, PLT</td>
</tr>
</tbody>
</table>

(Reference STS-109 FDF Flight Supplement)
Current ISS Inventory Concept

- The Inventory Management System (IMS) is used to track items on the ISS.
- Handheld barcode reader is used by the crew for quick on-site updates.
- Data from the barcode reader may be passed to the onboard IMS database by RF or serial hardline connection to the laptop.
- Expedition 15 will use the new PDAs to access IMS and perform barcode scans.
- IMS software application is used for complex updates.
- Manual crew entries into onboard database on laptop.
- Flight control team entries into ground database.
- Databases are synchronized by uplinking and downlinking “Delta Files.”
Space Station RFID Test 2008

- Objectives:
  - flight certify a commercial RFID interrogator and tags
  - demonstrate RFID inventory of crew items and office supplies at bag and item level

ISS Shampoo with tag

Time Domain Signal (tag on shampoo)
Pulses contain ID code
RFID – Lunar Outpost

• High probability applications
  – Inventory management
    • Crew supplies (e.g., personal items, office supplies, clothing)
    • Food, medicine
  – Real-Time Localization
    • EVA tools, equipment
  – Monitoring/verifying inter-habitat supply transfers
  – “Boneyard” inventory
    • Real-time access to surplus parts

• Smart tag and other potential applications
  – Monitor tool exposure limits and provide warnings (e.g., temperature extremes, shocks)
  – Storage of calibration information on sensors, LRUs
  – Passive tag tracking

Example: passive COTS tag with 64 bit ID code, temperature and range telemetry
Active UWB RFID for Tracking Applications

- Evaluate UWB-RFID system Sapphire DART
- Customize the system and enhance the tracking performance
• Laboratory test configuration for Sapphire DART

UWB Precision Tracking
UWB Precision Tracking

- UWB TDOA high resolution proximity tracking for robonaut
  - Theoretical analysis and simulation for TDOA proximity applications
  - Lab tests show sub-inch tracking resolution
Passive, Wireless Sensors

- Where possible, no-batteries
- Reduces wire, crew time, certification costs, weight, power, and size
- Numerous conceivable applications

- 64-bit SAW-based COTS RFID tag
- AirGATE Technologies / CTR tag
- 8-bit SAW-based COTS RFID tag

Potential applications for wireless ice sensor system
Passive sensor arrays (enlarged)
Ice sensor
Interrogator
• 70 MHz SAW-based sensors
  – G. Studor (JSC), R. Brocato (SNL), et al
• Key advantage: integrates existing sensor types into passive, wireless system
• Targeted application: micrometeoroid impact detection
• Requires efficient, miniaturized antennas
**HF Antennas**

- **Significant size reduction of the antenna**
  - Half-wave dipole \((0.5\lambda_0, 2.14\text{m})\)
  - Miniaturized spiral-loaded slot antenna & ground plane
    \((0.07\lambda_0 \times 0.11\lambda_0, 0.3\text{m} \times 0.46\text{m})\)

- **Habitat walls are electrically conductive**
  - Cannot use wire antenna directly against conducting wall
  - Integration of miniaturized HF antenna with habitat walls
    - E-textile antennas

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*EIGER Simulation*
HF Passive Sensor Antennas

- Miniature Spiral-Loaded Slot Antenna

Prototype 4
(45.7cm x 30.5cm x 0.32cm)

- 2.5% BW Gain > -5dBi
Coupling between two 70MHz antennas

- Received power levels at different locations in the mockup
- Model effects of blockage with equipment in habitat module
NASA Use of 2.4 ISM SAW-Based RFID

Courtesy AirGATE Technologies

Courtesy RFSAW, Inc.
RF Collision Avoidance Methods

- Spatial diversity through adaptive digital beamforming

- Chamber A: Vacuum and Thermal Cycle Testing of Flight Hardware

- Objective: replace wired thermal and pressure sensors with wireless sensors
  - Reduces setup time between vehicle configuration changes

- Stage: feasibility assessment

- Thermal limit cold side: 20K

- Applications for vibration and acoustic facilities are also being explored

Approximate dimensions
Environmental Facility Wireless Sensors

- Adaptive interrogation of wireless temperature and pressure sensors
- Goals: $T_{\text{low}} = 20K$; 1000s of T-sensors; 100s of P-sensors

72-Element, S-Band, Adaptive, Digital Beamforming for Tag Interrogation

JSC Chamber A
(Vacuum & Thermal Cycle)
Antenna System Approach

• No active sensor system elements inside the chamber

• Adaptive digital beamforming offers many design degrees of freedom
  – The system can learn optimal channel weighting coefficients prior to commencement of tests

• Interrogator aperture:
  – Small transmit aperture - attempt to minimize transmit directivity
  – Large receive aperture – high directivity for spatial diversity

• Additional collision avoidance obtained through:
  – polarization division and code division
Small Transmit Aperture for Broad Illumination
Large Receive Aperture for Spatial Diversity

- Digital samples on each receive element
- Beams are formed digitally
  - number of simultaneous beams limited only by external processors
- All tags within transmit beam are read by multiple, simultaneous receive beams
Example of Spatial Diversity: Schelkunoff array

Chamber Simulation
Tag 5

8 Element Schelkunoff Array
Patch width = 4.14 cm
Substrate thickness = .445 cm
Element spacing: $d = .62 \lambda$
Beamforming and Temperature Sensor Demo

AirGATE Technologies / CTR tag + slot antenna

Graphs showing performance comparison between 4-element beamforming and single antenna with dB levels.

Graphs also show temperature data with two different temperatures labeled as Temp 1 and Temp 2.
Conductive fabric circuits and antennas can be manufactured in an art-to-part process (e.g., see NASA MSC-24332, DARPA efforts)

Performance can be indistinguishable from conventional counterparts for many circuits, including RF/microwave circuits and antennas

- Equiangular spiral
- Microstrip patch antennas
- Quadrature hybrid coupler

E-Textiles for Wireless & RFID

![Graph showing RHCP Gain (dBic) vs. Phase angle at 4.0 GHz for Copper, Fabric, and Simulation]