Radio Frequency Identification: Tracking ISS Consumables

Presentation Overview

- **Contents**
  - **Room for Improvement**
  - **Radio Frequency Identification**
  - **ISS Constraints**
  - **DO5 Proposal**
  - **RFID Technology**
  - **Recommendation**
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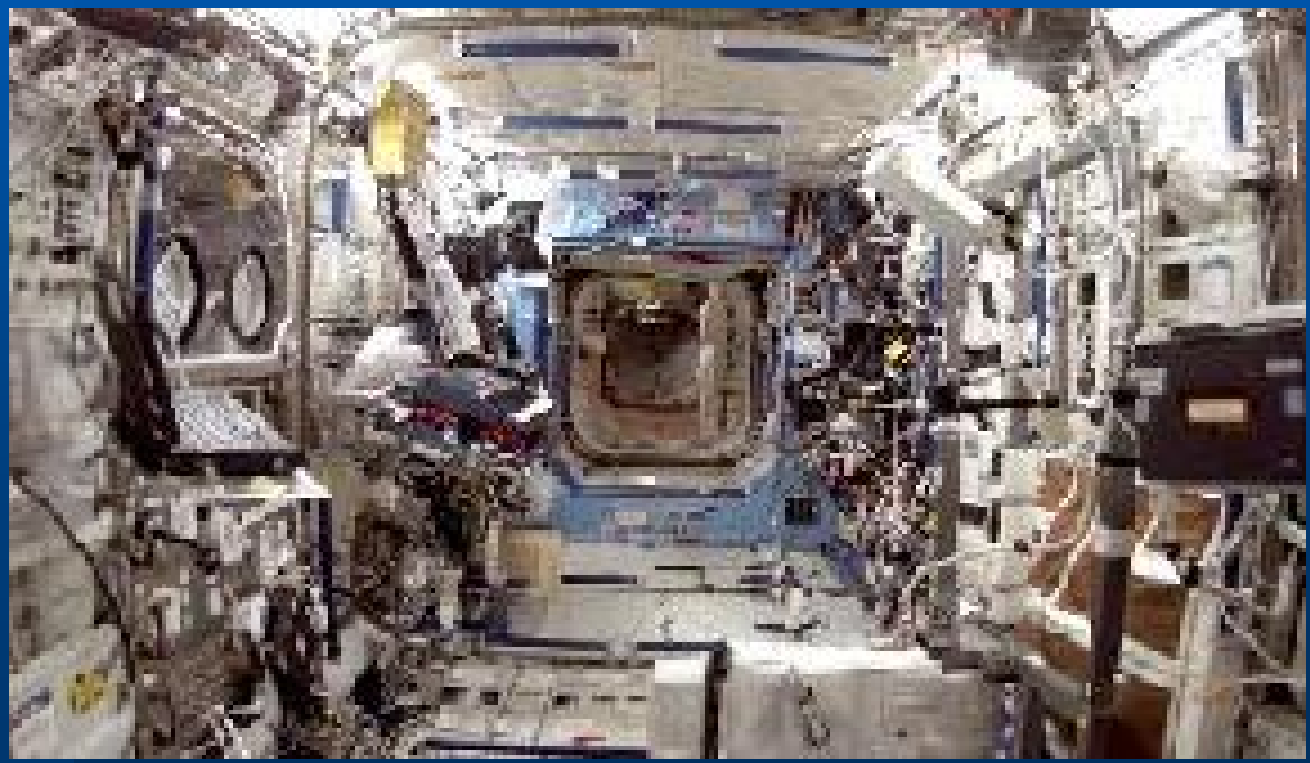
Room for Improvement

- **The Inventory Management System (IMS) is used by the crew to locate items on the ISS**
  - **IMS software application on a laptop is used for complex updates**
  - **Handheld barcode reader (BCR) is used for quick on-site updates**

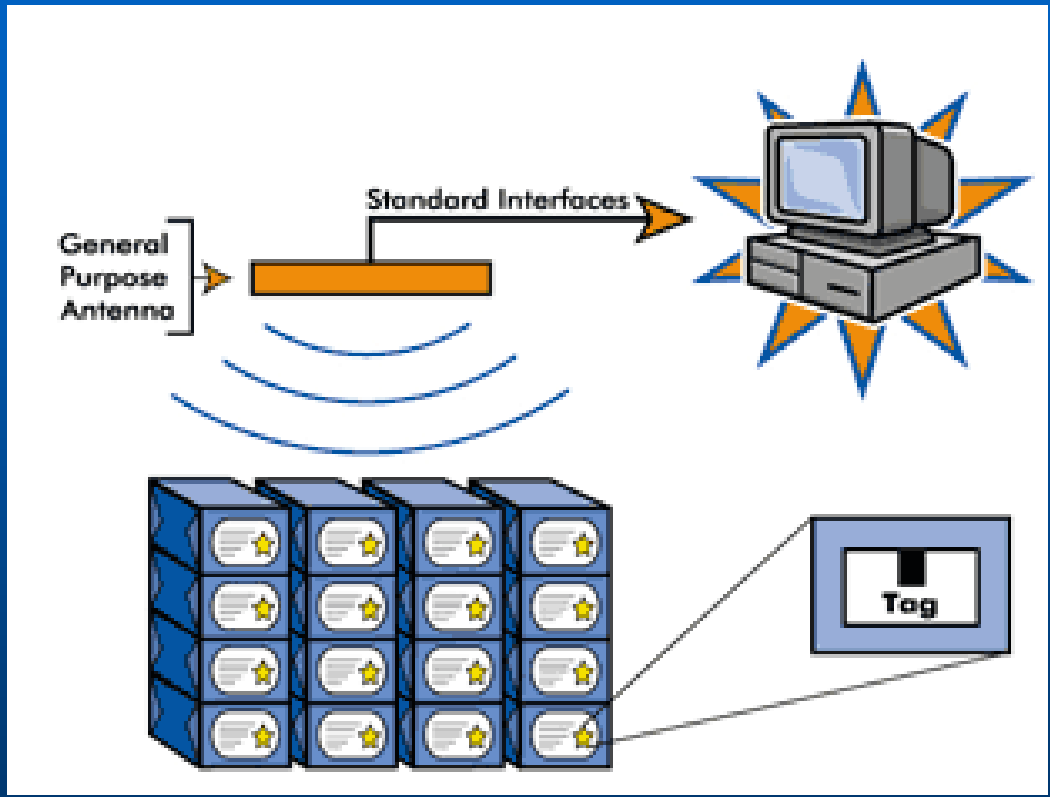


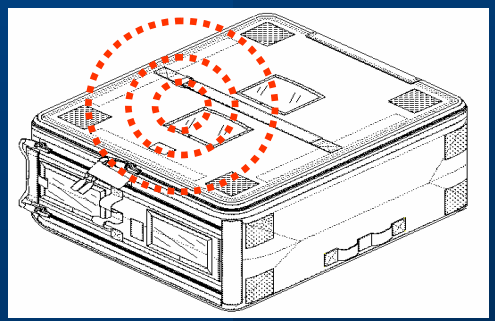
Room for Improvement, cont.

- **IMS is only as good as the data entered into it**
- **Crew time is required to account for every single item using both the BCR and IMS application**
  - **The timeline provides the crew 40 minutes per day to update IMS**
  - **The BCR works great…IF everything has a barcode and all items are scanned when moved**
  - **2.88% of all U.S. items are currently lost and more are probably not in their reported location (202 out of 7007 items)**
    - **Includes items of high and low criticality; some of which have a possible search location**
- **ISO assists Consumables Team with dry goods audits and maintains website with separate files for each audit**
  - **Consumables are only tracked to bag level in IMS**

Radio Frequency Identification

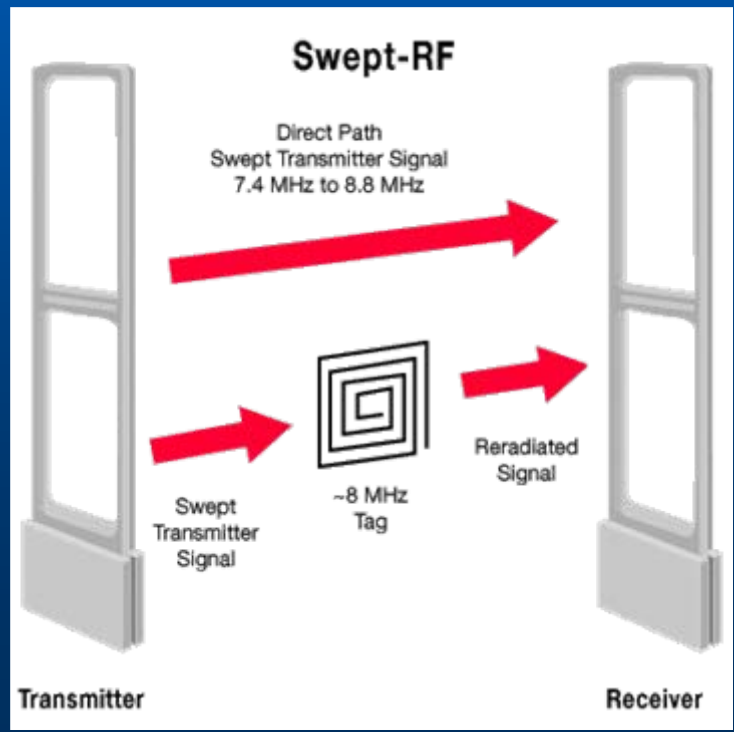
- **Radio Frequency Identification (RFID) technology allows for non-contact recognition of objects with RFID tags**
  - **Non line-of-sight system enables the contents of a CTB to be scanned without having to be opened**





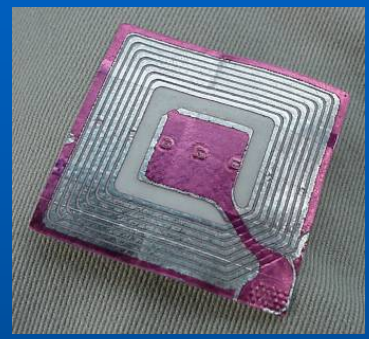
Applications of RFID

- Secure Access Control
- Inventory Tracking
- Exxon/Mobil Speedpass
- Electronic Toll Collecting
- Animal Tracking
- Smart Shelves
- Electronic Article Surveillance (EAS)
  - clothing stores, libraries
  - 2 - 10 MHz, up to 80 inches between gates

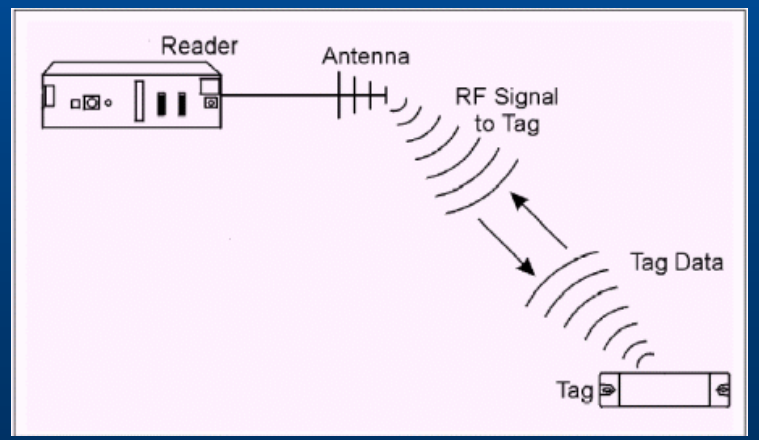


How RFID Systems Work

1. The antenna of the interrogator (reader) emits radio signals
   - EM field transmitted can be continuous
   - Antennas come in a variety of shapes/sizes
     - Can be built-in or external
     - Circular polarization of reader antenna allows any tag antenna orientation
   - Range: 1 inch to 100+ feet



2. Transponders (tags) respond with their unique code
   - Microchip / Integrated Circuit
   - Antenna: copper or aluminum coil
   - Encapsulating material: glass or polymer



3. Reader receives and decodes tag information and sends it to a computer via standard interfaces
   - Fixed or portable
   - Software available to filter data and monitor the network

System Considerations

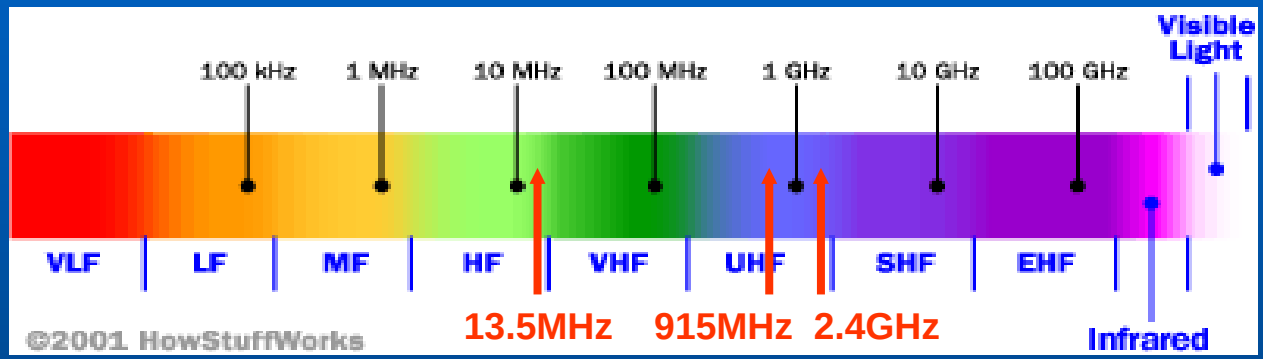
- **Active vs. Passive**
- **RF Considerations**
- **ISS Constraints**

Active vs. Passive Tags

- **Active Tags**
  - Battery powered – would require periodic replacement/recharging
  - Typically read/write, up to 1MB of memory
  - Greater range (30 meters possible with UHF)
  - Limited operational life: depends on operating temp. and battery
  - Ultra Wide Band (UWB) systems use time difference of arrival of transmitted pulses to triangulate position
- **Passive Tags**
  - Powered by energy transmitted by reader
  - Typically read only, 32 – several Kbytes of memory
  - Virtually unlimited lifetime, lighter, smaller, and cheaper
  - 13.56 MHz tags powered by inductive coupling
    - EM field emitted by the reader creates a voltage drop in the coil
    - Tag modulates the signal (amplitude/frequency/phase) and sends its unique code back to the reader
  - UHF tags (915 MHz and 2.45 GHz) powered by propagation coupling
    - Similar to 13.56 MHz tags, but since signal travels greater distances, field strength decreases with distance (depends on tag orientation and other factors)

RF Considerations

- **The Frequency Spectrum**



- **Regulation**
  - **National and Int'l. controls in development**
    - **FCC – regulates the use of all radio frequencies in the U.S.**
    - **ISM – unlicensed frequencies set aside for industrial, scientific and medical use, available around the world**
  - **JSC / Avionic Systems Division regulates RF use on the ISS**
    - **ISM band frequencies don't present any obvious hazards, but each system must be tested to ensure it won't interfere with other ISS systems (POC EV / Cathy Sham)**

RF Considerations, cont.

- Lower Frequencies
  - Lower cost tags
  - Higher performance around metals and liquids
- Higher Frequencies
  - More prone to reflection, refraction, and diffraction
  - High data transfer rate
  - Longer read ranges
  - Interference less of a problem with high frequencies
    - Frequency Hopping Spread Spectrum (FHSS) can be used to avoid interference
- Common RFID Frequencies (ISM Band)
  - 13.56 MHz
    - Range up to ~1.5 m with credit card sized tag
  - 915 MHz
    - Typical range up to ~3 m
  - 2.45 GHz
    - Typical Range up to ~5 m
    - BCR operates at this frequency

RF Considerations, cont.

- **Range**
  - **Longer range with larger antenna, higher power, frequency, and cost**
  - **Limited by environmental conditions and metal obstacles**
- **Standards**
  - **ISO – some standards for some frequencies, e.g. ISO 15693 and ISO 18000**
  - **EPC – Auto-ID Center's Electronic Product Code could replace the UPC as the standard for UHF; 64 or 96 bits of information is stored in a specified format, allowing for billions of unique serial numbers**
  - **Performance of ISO and EPC-compliant tags should be similar, but sticking to standards increases flexibility of technology in the future**

ISS Constraints

- **Minimal use of ISS resources**
  - **Power (Fixed readers need supply of 5 - 24 VDC, 1.2A)**
  - **Volume, Mass**
- **Minimal crew interaction**
  - **Setup, maintenance and use**
  - **Tags must be easy to attach and unobtrusive**
  - **System certified for 15 years minimum**
- **No RF interference with US/RS systems**
- **Environmental Conditions**
  - **Shock and Vibration during launch**
  - **Inside ISS (per Flight Rules B17-8 and 9)**
    - **Temp: 64 to 93ºF (17.7 to 33.9ºC)**
    - **Humidity: ranges from 25% to 75%**
  - **Outside ISS (RFID tags on EVA tools, reader not used)**
    - **Larger ambient temperature range**
    - **Vacuum**

ISS Stowage

- **Current stowage (SSP 50621 rev D): 627 CTBEs**
  - **612 CTBEs in standard and non-standard US stowage**
  - **15 CTBEs in SM; 43 CTBEs in Docking Compartment 1**
- **Projected stowage: 354 CTBEs**
  - **Node 2: 4 ZSRs holding 72 CTBEs (assume 1 ZSR holds 18 CTBEs)**
  - **NASDA**
    - **JEM: 3 stowage racks + potential niche space**
    - **ELM: 8 system and utilization stowage racks**
    - **Total: 198 CTBEs**
  - **ESA**
    - **Columbus: 3 ZSRs plus 1.01 m^3 between system racks**
    - **Total: 84 CTBEs**
- **Grand total of current and projected stowage: 981 CTBEs**
  - **Break down into halves, doubles, triples to get number of RFID tags required to track just CTBs**

Node 1 Stowage

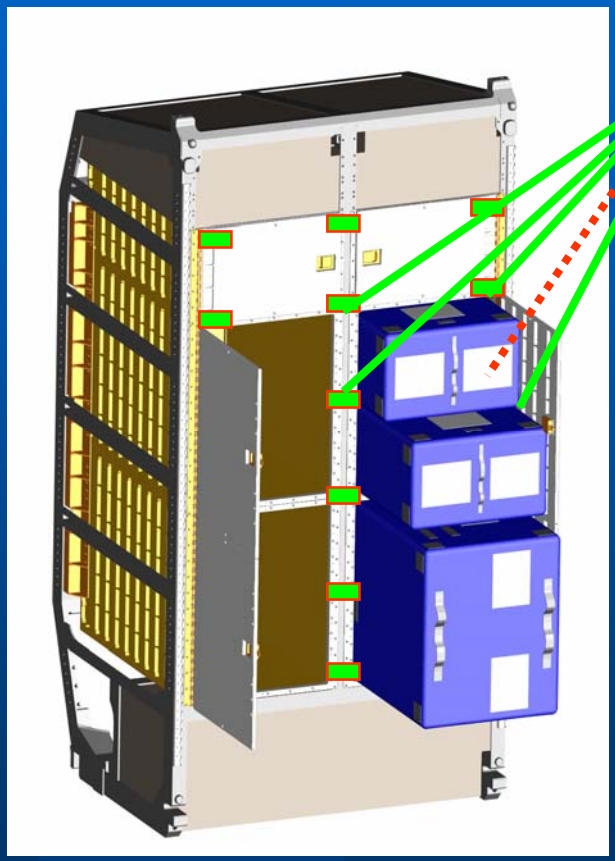
DO5 Proposal

- **Stowage Applications**
- **Initial Application Recommendation**
  - **How Would it Work?**
  - **Who Would Benefit?**
  - **Crew Time Spent on Audits**
  - **Tagging Consumables**
  - **Challenges Identified**

Stowage Application #1:
Hatch Transfer

- **The idea:**
  - **One or two readers at hatches detect tags on all items on the transfer list**
- **Technology in use today**
  - **Warehouses**
  - **Libraries**
  - **Clothing Stores**
- **Simple proof of concept test**
  - **CB / Marsha Ivins suggested comparing transfer list with RFID results as a DTO**
- **Location tracking down to module level only**
  - **ISO team concluded this was not the most helpful use of the technology**

Stowage Application #2:
Stowage Location Tags



- **The idea:**
  - **– Crewmembers use a portable reader (handheld, wearable, free floating, etc.) to scan regions**
  - **– Software determines position of items in relation to tags on racks/shelves**
- **Challenges:**
  - **– Crew time-intensive to tag all items and locations**
  - **– Higher fidelity location resolution requires more tags on locations**
  - **– Metallic environment would be a complex engineering task (multi-path issue)**
  - **– Handheld systems are available today, but we would need to program a position determining algorithm**

Stowage Application #3: Smart Drawers

- **The idea:**
  - **Antenna integrated into rack shelf (or sewn into CTB)**
  - **Items with tags trigger the antenna as they are moved between bags/racks**
  - **Advantage of high location resolution**
- **CB / Paolo Napoli recalled how ESA tested this type of system 10 years ago**
  - **Database was updated with the movement of tools between drawers with a timestamp**
  - **Suggested astronauts could wear bracelets to identify who moved the item**
- **Technology should be improved, but still presents challenges:**
  - **RFID tags on all items tracked**
  - **Attaching the antenna to racks or integrating into the CTB**
  - **Multiple readers may get expensive or consume too much power**

Stowage Application #4: Internal GPS

- **The idea:**
  - **Fixed readers placed strategically around query periodically or constantly for surrounding tags**
  - **Multiple antennas receive the tag signals**
  - **Software translates tag responses into a 3-D coordinate, matched with a location in the ISS, using triangulation**
- **Technology does not appear to be here quite yet**
  - **Intelligent Automation, Inc. currently developing system to track astronauts during EVA using time-modulated UWB**
- **Even if technology is developed in near future, there are obstacles to overcome**
  - **Resolution may not be better than rack level due to metallic environment**
  - **Very expensive system**
  - **Initially crew time intensive: setting up readers and attaching tags to all items we wish to track**

Initial Application Recommendation: Auditing Consumables

- **Crew scans tagged consumables with a handheld reader that automatically updates a database**
  - **Advantage of minimal crew interaction**
    - **Tagging to be done on the ground**
    - **Eliminates hand counts**
- **Requires:**
  - **Tags on all consumables to audit**
  - **Handheld reader**
  - **Ground testing and hardware certification**
  - **Crew training**
  - **Ground support to tag items and monitor data**
- **Could supplement IMS with location tracking in the future**
  - **Experiment with the technology while benefiting the program**
- **Recommend this application be implemented**

How Would it Work?

- **Tags placed on manifested consumables on the ground**
  - **Eliminates need for crew to spend time tagging items**
  - **Modify process of barcode label application so all RFID tagging is done at the same point on the ground**
- **Transition period when tagged items are mixed with untagged items in orbit**
  - **Some items will be consumed over many increments**
  - **Crew must tag all consumables currently on orbit or perform an initial count and keep track of these items when using the handheld scanner**
- **Onboard database automatically updated each time crewmember scans an area**
  - **Ground downlinks data regularly or when necessary**
  - **Not integrated with IMS until location tracking technology proven to work in ISS environment**

Who Would Benefit?

- **Expedition Crews**
  - **Save time and effort on logistics work, leaving more time for science**
- **Crew Provisions Office**
  - **More efficient and accurate planning of resupply missions**
    - **More space to launch payloads and critical hardware**
    - **Better predictions of what crew uses and at what rate**
- **ISO Team**
  - **Validation of existing IMS entries**
  - **Allows consumables to be tracked with more detail than CTB level**

Crew Time Spent on Audits

- **"Beginning with Expedition 6, increased importance has been placed on accurate auditing of crew consumables. This is only expected to increase over the life of the station. Expedition 6 spent approximately 12 hours* auditing consumable data; this could be lessened with judicious use of an automated system."**

  **** Not including Russian or personal hygiene items***

- **Expedition 6 Audits**

  Consumables:

  4:00 - Crew provisions audit (pantry items)
  0:45 - Photo/TV film audit
  7:00 - Crew clothing audit
  0:50 - Trash bag liner and urine pre-filters

  Other:

  6:00 - Node 1 audit
  6:00 - Lab audit
  2:30 - Lost items audit

- **Less audit time means more time can be allocated for science ops!**

Tagging Consumables

- **Items to be tagged**
  - Office Supplies
  - Towels/Napkins
  - Printer Supplies
  - Batteries
  - Hygiene Items
  - Crew Clothing
  - Photo/TV
  - Food

- **Information that can be stored on the tags**
  - Unique identifier that matches up with database entry (similar to IMS format)
  - Room for other information such as launch/expiration date
  - Yet to be determined

Challenges Identified

- Tag reliability and ensuring tags do not fall off
  - Determined by tests or long-term use
- Extreme environment (EVAs, launch vehicles)
  - May need to encapsulate tags
- Encouraging Russians to adopt our new system
- Tagging small items may be difficult or impossible
- Metallic items reflect RF signals
  - 915 MHz should work with a 1/8“ – 1/4” gap; this can be achieved by using Scotch double sided thick tape or attaching like a clothing price tag
  - Metallic enclosures (food containers and RSRs) will block all transmission unless partially opened
  - Multi-path protocols can prevent many problems
- Objects with high water content can reflect or absorb RF signals
  - Lower frequencies penetrate better in good conductors
- Good system design and engineering can overcome these challenges, but <u>experimentation</u> is essential

RFID Technology

- **Many RFID companies emerging**
  - **Lots of R&D, e.g. Sandia, Invocon, Univ. Pittsburgh, MIT, IAI**
  - **Many proven commercial technologies for common applications**
  - **Many companies think ISS inventory tracking would be possible, but none had a clear solution for our unique challenge of location tracking**
  - **Off the shelf technology should be able to conduct audits with minimal modifications**
  - **Many adopted and developing standards**
- **Difficult to predict performance in the ISS environment without tests**

RFID System Costs

- Wide range of hardware costs
  - Passive tags $ 0.40 - $8 depending on complexity, size and quantity, but prices may drop 5 cents next year and under 1 cent a few years later
  - Readers $200 and up
- Add cost of hardware certification and crew training
- Barcode reader estimates for comparison
  - Hardware costs
    - Units $2000 at the time, multiple units purchased, 4 onboard ISS
    - Barcode labels 20 – 30 cents each
    - Metal photo labels (can withstand temp. extremes) about $1 each
  - Crew training (time per crew member)
    - 1.25 hours for the BCR Ops lesson
    - ~3-4 hours for crew consultations
    - ~3 hours in other lessons
    - ~5-7 hours in simulations
    - Total: approx. 14 hours per crew member

Recommendation

- **Experiment with a development / evaluation kit**
  - **Ideally, a handheld with an integrated barcode and RFID function**
  - **All frequencies have pros and cons; 915 MHz may be a good compromise**
  - **A range of 2 – 3 m should be sufficient for rack depth queries**
  - **Sticking to standards increases flexibility of technology in the future, e.g. ISO or EPC compliant tags**
- **For example, RFID Wizards has products available from a variety of manufacturers**
  - **Tags $1 – 1.25**

MPR-1510 915 MHz Handheld Reader with barcode scanner option and 100 assorted EPC tags

Read range: 18 in

$2,729

FEIG 13.56 MHz Handheld Reader Dev Kit with 25 tags

Read range: 7 in

$625

Proposed Testing

- **Scan various consumables in various stowage locations**
  - **Fill CTBs with metallic / non-metallic / moist / dry items**
  - **CTBs in ZSRs**
  - **CTBs in RSRs with doors open and closed**
  - **Stacked metal food containers**
- **Determine**
  - **Range required**
  - **Accuracy of results**
  - **Time to conduct audit**
  - **Ease of process**
- **Use results to design prototype for other applications**
  - **Hatch transfer may be simplest design, but less useful**
  - **Other concepts feasible if limited amount of items tagged**

Resources

- **The use of RFID on the ISS will be driven by interest and funding**
- **Possible funding options**
  - **Center Director Discretionary Funds**
  - **ISS Program Office: Station Development Test Objective (SDTO) (**SSCN3886.doc provides guidelines)
  - **SBIR (Small Business Innovation Research) Program –** provides up to $850,000 in early-stage R&D funding directly to small technology companies
  - **STTR (Small Business Technology TRansfer) Program –** provides up to $600,000 in early-stage R&D funding directly to small companies working cooperatively with researchers at universities and other research institutions

Resources

- **Testing facilities**
  - **B9 ISS Mockup Facility**
  - **SSC Computer Lab**
  - **B29 Long Duration Evaluation Facility (Integrity Facility, Bio-Plex)**
    - **High-fidelity test facility for research of technologies, techniques, and procedures pertinent to future planetary missions**
  - **NEEMO – The "Aquarius" Undersea Research Habitat**
    - **Unique research facility owned and operated by the NOAA**
      - **Approx. size and layout of an ISS module (e.g. Lab or SM) with a highly developed infastructure including communications, telemetry, life support and electrical systems**
    - **A MOR (Mission Objective Request) must be submitted (http://mod.jsc.nasa.gov/dt/Schd/NEEMO/NEEMO.htm)**

The Future of RFID...on the ISS and Beyond

- Tagging consumables is just the first step
  - Operationally simple and immediate use
- Future capabilities to add
  - Track all items by location as supplement to IMS
  - Find lost items
- RFID technology is an ever-changing field
  - Standards and regulations are being developed
  - More companies researching and producing RFID for a wide range of applications
  - Tags getting cheaper and smaller

Backup Slides

- **Current RFID R&D**
- **Hardware Available from Various RFID Companies**
- **Acknowledgments**

Current RFID R&D

- **Auto-ID Center**
  - Industry-funded research program creating standards such as the EPC and developing software needed to track items using small, low cost RFID tags
  - Designing 915 MHz chips that will cost around 5 cents when produced and bulk, can be read from at least 4 feet, and use EEPROM (electrically erasable programmable read-only memory) so that tag data can be overwritten with a special electronic process
- **Sandia**
  - Developing Programmable SAW (Surface Acoustic Wave) correlator tags; promising research but still in early stages and not focused on determining location
- **Invocon**
  - Internal Wireless Instrumentation System (IWIS) sensors used on station
  - Shuttle Wireless Instrumentation System (SWIS) sensors used on shuttle
  - Working on handheld system for Sandia's technology
  - Has written white paper on hatch transfers: commercial tags (i.e. Atmel) and custom readers needed
  - Has considered an SBIR for an integrated crew positioning system, leak detection system, and inventory management system
- **University of Pittsburgh**
  - Developing PENI tag, 3 cubic mm
  - 12 cents each
  - PC compatible PEMI receivers currently sell for less than $50.00

Available from InTrak

- **Same core systems as WhereNet and Ekahau, but could add location tracking capability in the future using TDOA (time difference of arrival) technology**
  - **Auditing system**
    - **Passive tags**
      - **0.5 inch square,**
      - **$3 each**
      - **900 MHz, 2.4 GHz, and 5.7 GHz available**
    - **Handheld reader**
      - **range of 50 – 100 feet**
      - **several hundred dollars**
      - **Hardware off-the-shelf; customizable software**
  - **Location tracking system**
    - **Active Tags**
      - **1 inch square, 1 cm high**
      - **$5 each**
    - **Fixed reader**
      - **Fixed receiver every ~150 ft. throughout station**
      - **$50 each**

Available from Texas Instruments

- **TI does not sell handhelds, but 3rd party Team Tag-it members do**
- **Low frequency transponders**
  - **134.2 kHz**
  - **Easily converted into labels (flat); variety of shapes/sizes**
  - **$2 - $4 each**
  - **Mount-on-metal transponders**
    - **102 x 36 x 16.5 mm**
    - **$8 - $5 each**
- **Tag-it Inlays**
  - **High frequency: 13.56 MHz**
  - **Reels of 5000: $2000 - $2500; 40 – 50 cents each**
- **Fixed readers $200 each, plus cost of antennas**

Available from Northern Apex

- **RFID function integrates into Palm or Pocket PC platform**
  - **Recommended VECTOR dev kit**
    - **13.56 MHz reader has built in barcode reader**
    - **Range of a few inches**
    - **Tags $1.83 – $4.50 depending on quantity and encapsulation**
    - **Reader sled: $390 - $735**
    - **Software: $1995**
    - **Pocket PC / Palm: $425**
  - **900 MHz Matrix handheld reader with larger range in development**

Available from Intermec

- **Intellitag Pallet/Carton RFID Evaluation Kit (“Ready-to-Go”)**
- **$14,000**
- **Includes**
  - **Fixed and handheld system that support all relevant adopted and emerging national and international standards**
  - **Mobile wireless computer and software**
  - **A variety of sample tags**
  - **1 day onsite training**

Available from Tek Industries

- **TEK Protégé RFID Adapter is an attachable RFID scanner that snaps together with a Palm hand held unit**
  - **Reads/writes to RFID tags of multifrequencies and protocols**
    - **Industry standard 125Khz, 134.2Khz or 13.56Mhz RFID tags**
  - **Read range; 4 to 6 inches**
  - **Battery: 6 NiMH rechargeable cells**
  - **Carrier Frequencies: 125KhZ, 134.2Khz or 13.56Mhz**
  - **RF power: 200 mW**
  - **RS232 Downloading/Charging cable for PC and Laptops**
  - **Sample tags, scanner, and Palm handheld loaded with a demo program: $620**
- **Recommended 134.2 kHz and 13.56 MHz tags due to high surrounding metal content**

Available from EmbedTech

- **Laundry Tags**
  - **13.56 MHz**
  - **4.5 cm x 3.4 cm x 0.2 cm, 2.8 g**
  - **Multiple versions of this garment tag available**
    - **Different RFID inlays – recommended passive UHF for our read range**
    - **Encapsulated in different resins (stiff and soft resins)**
    - **Depending on quantity ordered, cost is < $1 each**
- **Handheld Readers**
  - **Palm with RFID "sled" or dedicated handheld**
  - **Cost $900 and dropping with more volume production**
  - **One supplier is offering an RFID "insert" card to a barcode reader for $300**
- **Experience in working around metal objects in several applications**
- **Quoted handheld and test tags for < $1000**