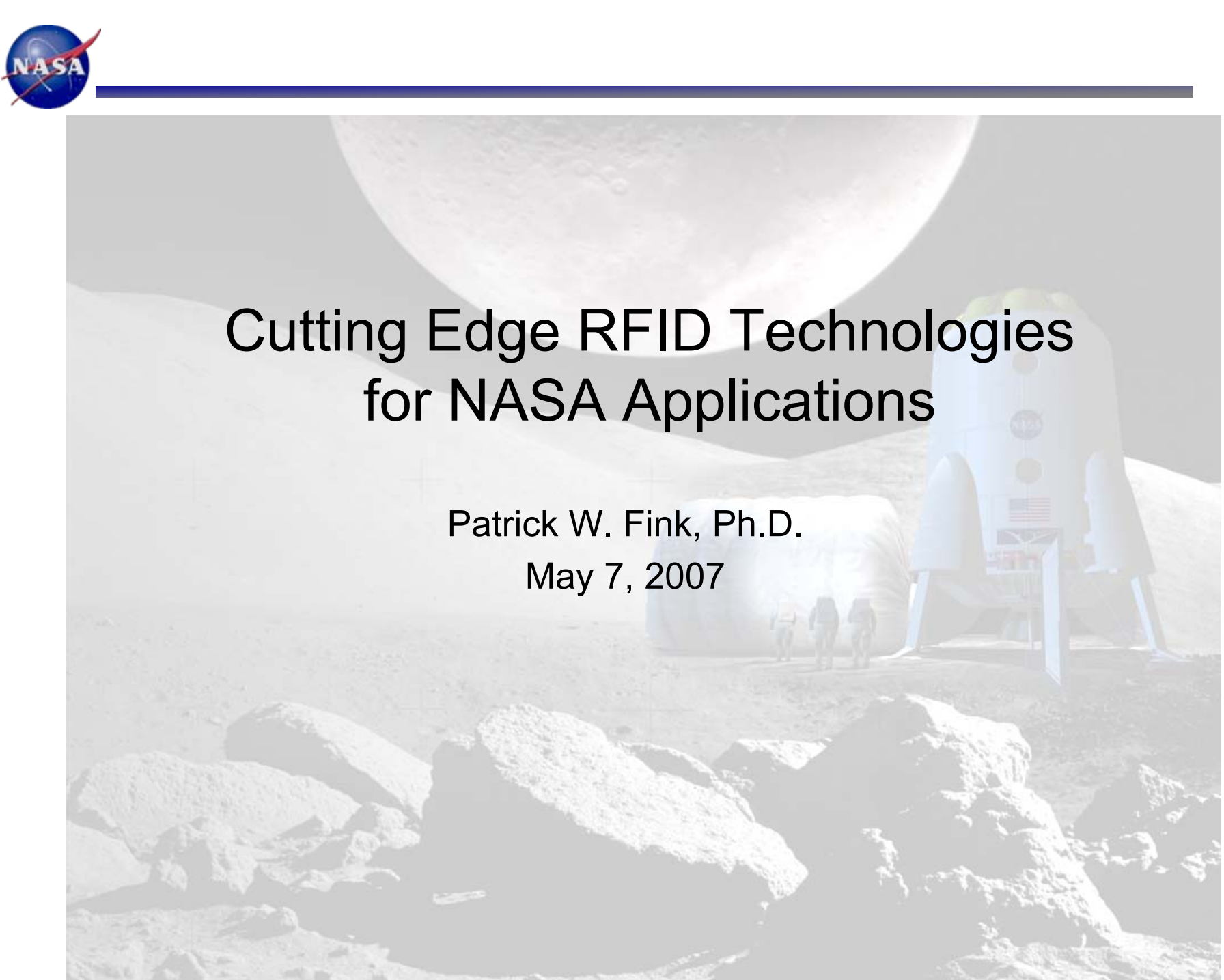

Cutting Edge RFID Technologies for NASA Applications

Patrick W. Fink, Ph.D.

May 7, 2007

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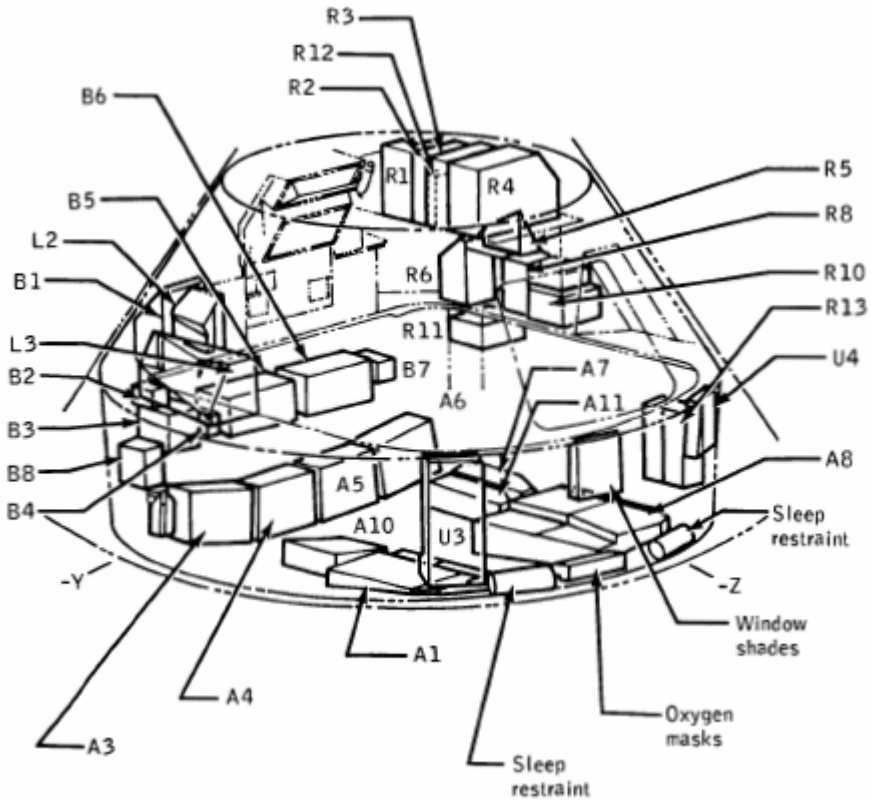
Outline

- 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

Stowage location (a)	Equipment	Quantity
A5	Headrest pads	3
	Heel restraints	3 pair
	Sleep restraint ropes	5
	Sextant adapter for 16-mm camera	1
	Spotmeter	1
	Two-speed timer	1
A6	Carbon dioxide absorbers	2
	Television monitor with cable and strap	1
	12-foot television cable with strap	1
	Television-camera bracket	1

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

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

STS–109 MIDDECK STOWAGE

FORWARD LOCKERS

MF14E
Food, Menu
FRED

MF14G
Clothing, CDR
Clothing, CDR

MF14H
Bags
- Helmet Stowage (2)
- Inflight Stowage, Restraint (10)
- Jettison Stowage (10)

Bungee, Adjustable (7)
Canister, WCS (Coffee Can)
Covers
- HUD (4)
- Parachute (7)

Hoses
- Personal Hygiene
- WCS Canister

MF14H
(Cont)
Kits
- Comm
  - Cables
    - Comm, 4 ft
    - Comm, 14 ft
  - Mic, Handheld (3)
  - VLHS (2)
- Saliva

Mirror (2)
O2 Bleed Orifice
Pip Pin (12)
Pip Pin, Escape Pole (Spare)
Switch Guard, Computer
Tape
- Gray, 1 in
- Gray, 2 in

Ziploc, 8 in (20)
Ziploc, 12 in (8)

MF14K
Air Bottles
Breaker Bar, 3/8 in
Breakout Box
Filter, Waste Water Dump
Kit, RMS D&C
Turnbuckles

MF14M
FDF | Bag, WVS

MF14O
Food, Menu
Food, Menu

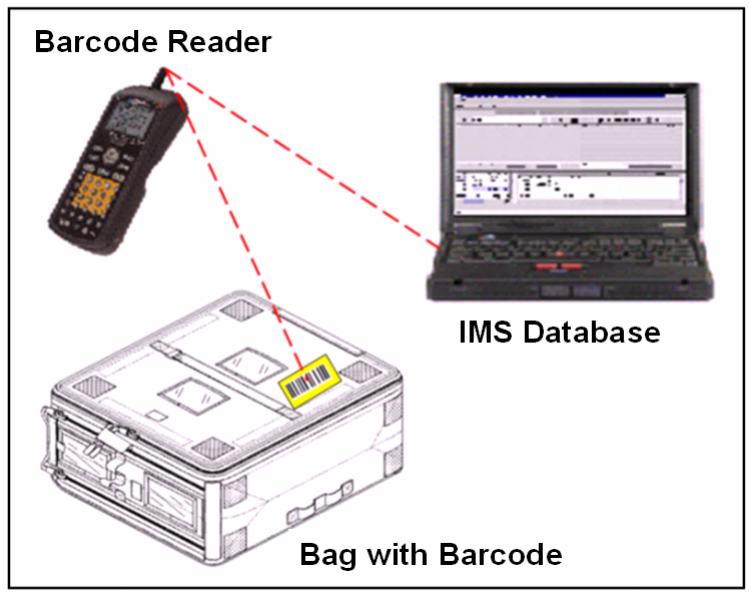
MF28E
Food, Menu
Food, Menu

MF28G
Clothing, PLT
Clothing, PLT

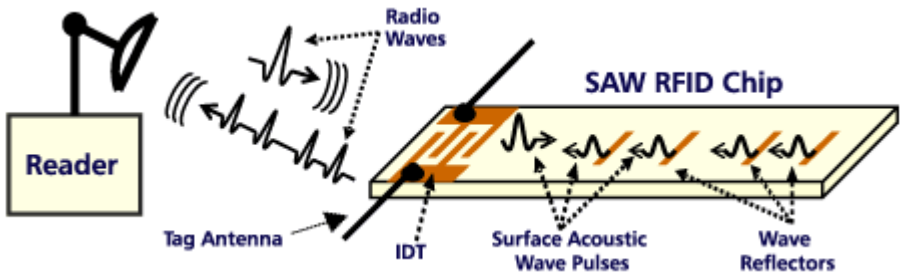
(Reference STS-109 FDF Flight Supplement)

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”



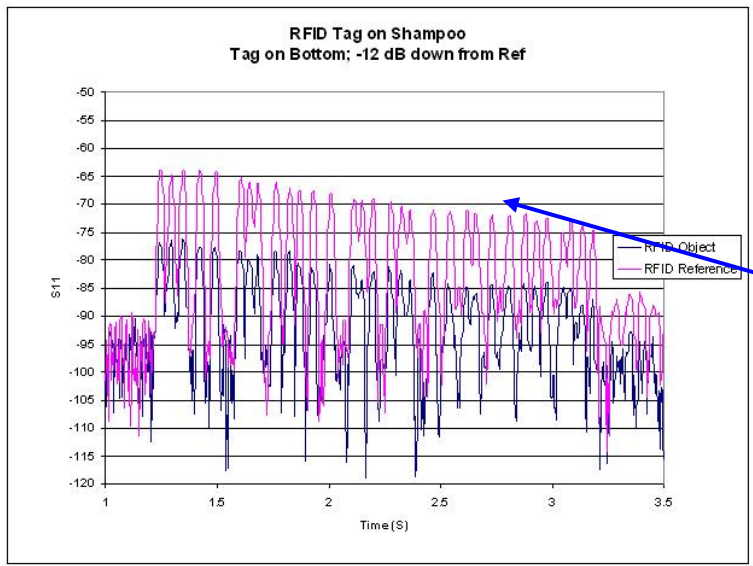
Space Station RFID Test 2008



RFSAW
One Tag Worldwide!

- 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

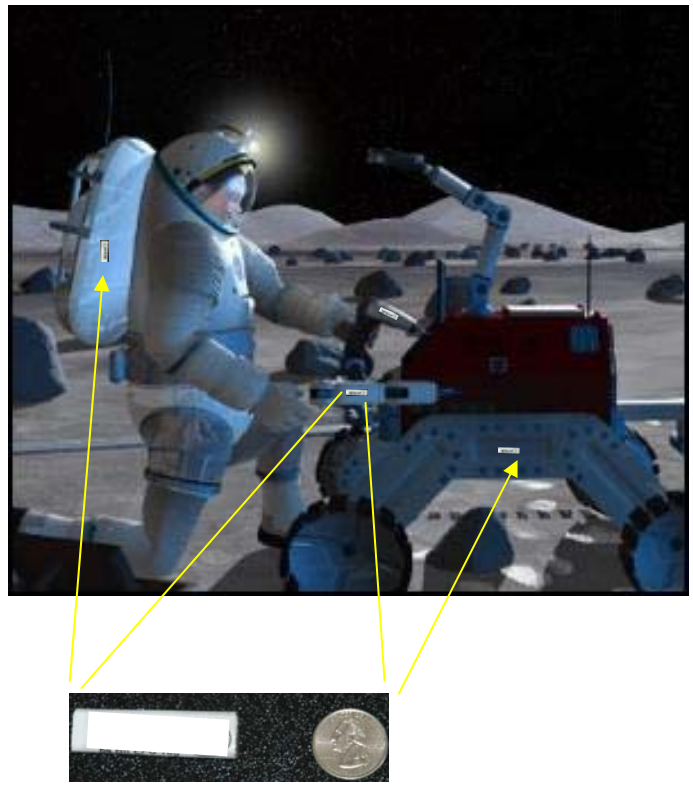


Time Domain Signal (tag on shampoo)

Pulses contain ID code

RFID – Lunar Outpost

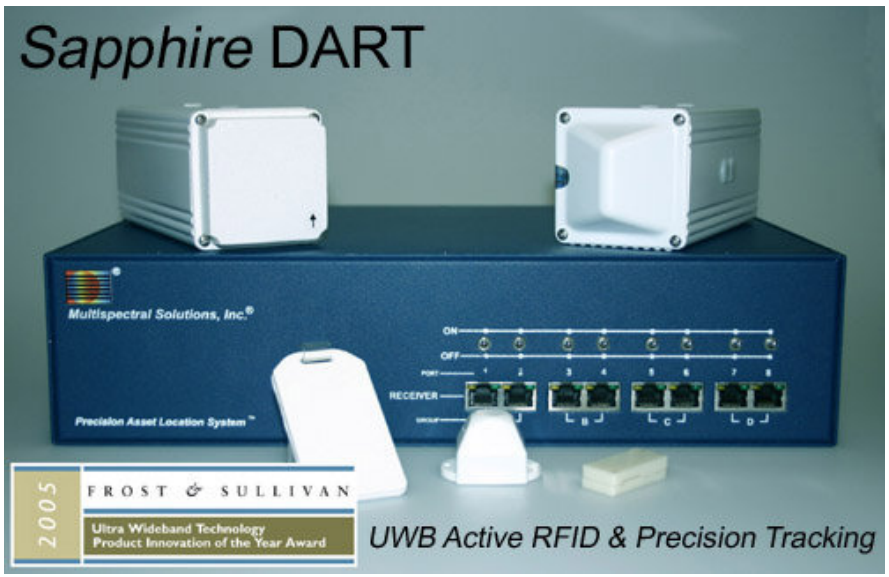
- High probability applications
  - Inventory management
    - Crew supplies (e.g., personal items, office supplies, clothing)
    - Food, medicine
  - Real-Time Localization
    - EVA tools, equipment
  - Monitoring/verifying inter-habitat supply transfers
  - “Boneyard” inventory
    - Real-time access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

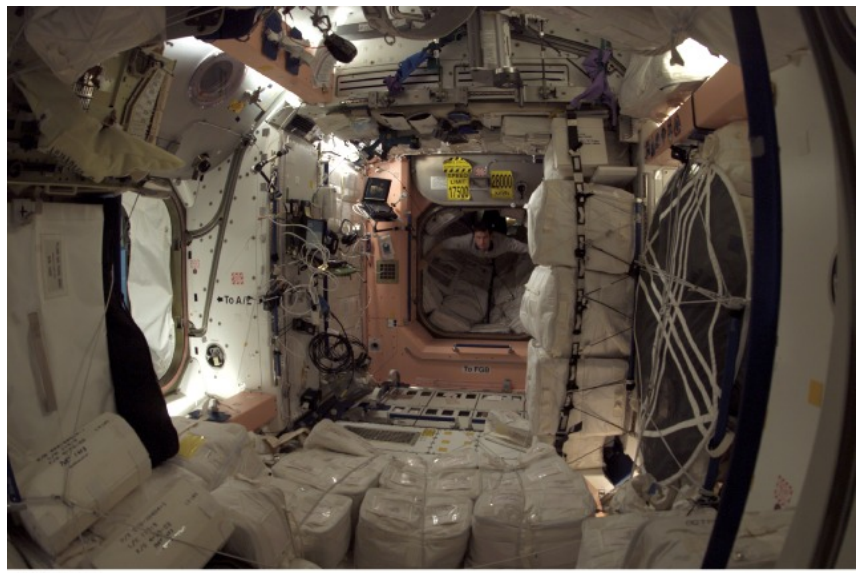


Example: passive COTS tag with 64 bit ID code, temperature and range telemetry

Active UWB RFID for Tracking Applications

- Evaluate UWB-RFID system Sapphire DART
- Customize the system and enhance the tracking performance

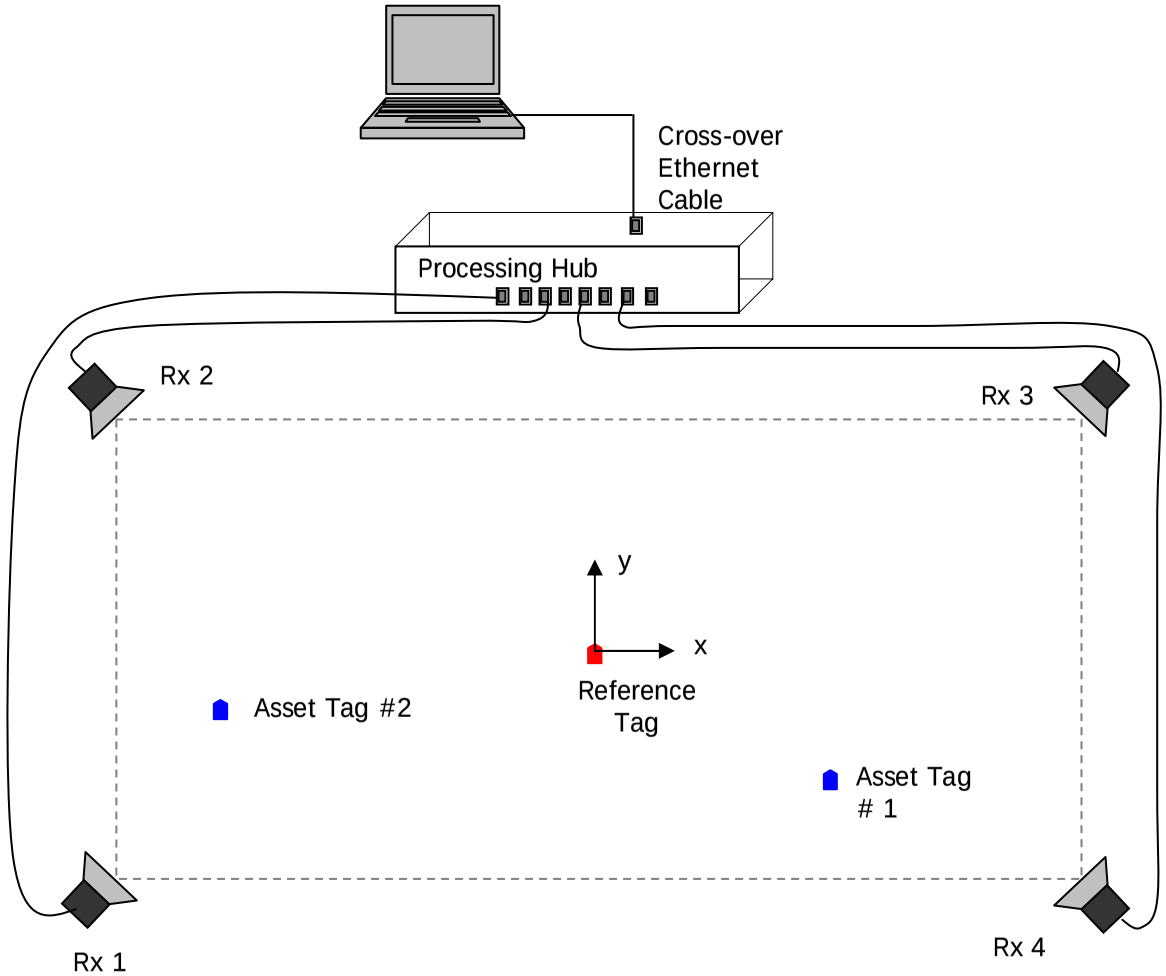




ISS007E11805

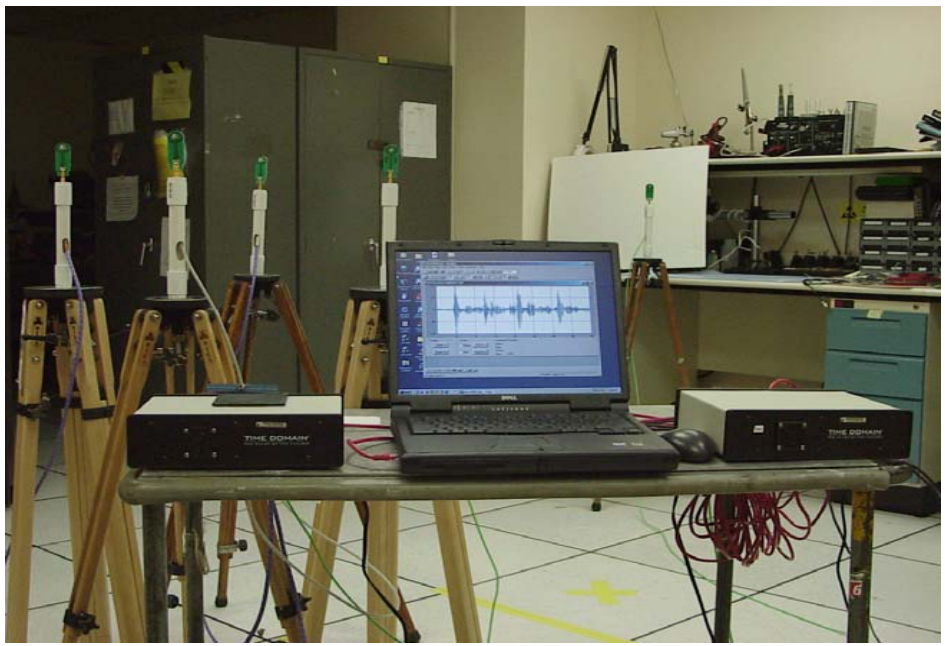
UWB Precision Tracking

- Laboratory test configuration for Sapphire DART



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

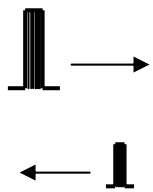
Potential applications for wireless ice sensor systen

Passive sensor arrays (enlarged)

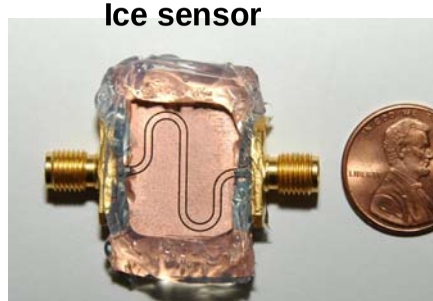
AirGATE Technologies / CTR tag

8-bit SAW-based COTS RFID tag

Interrogator

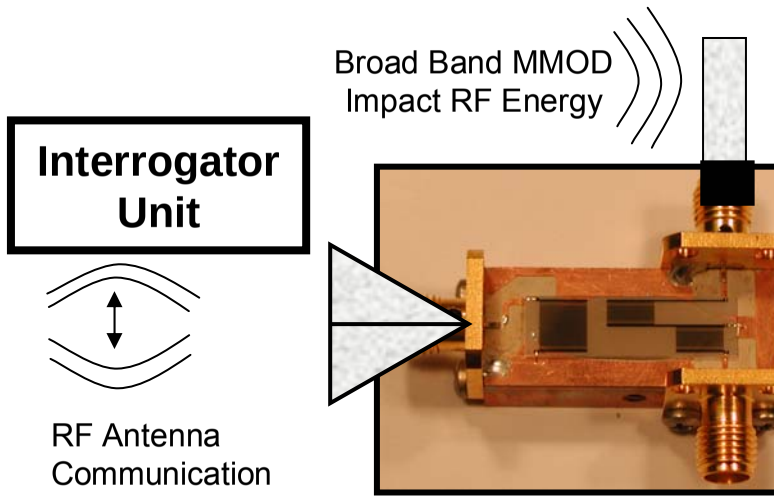


Ice sensor

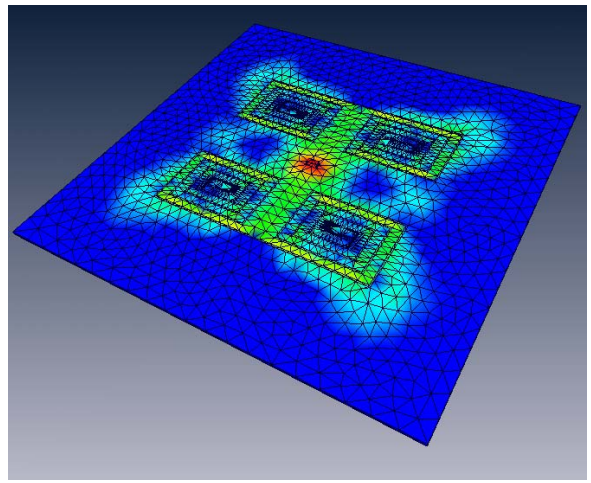


Antennas for HF SAW Sensor System

- 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



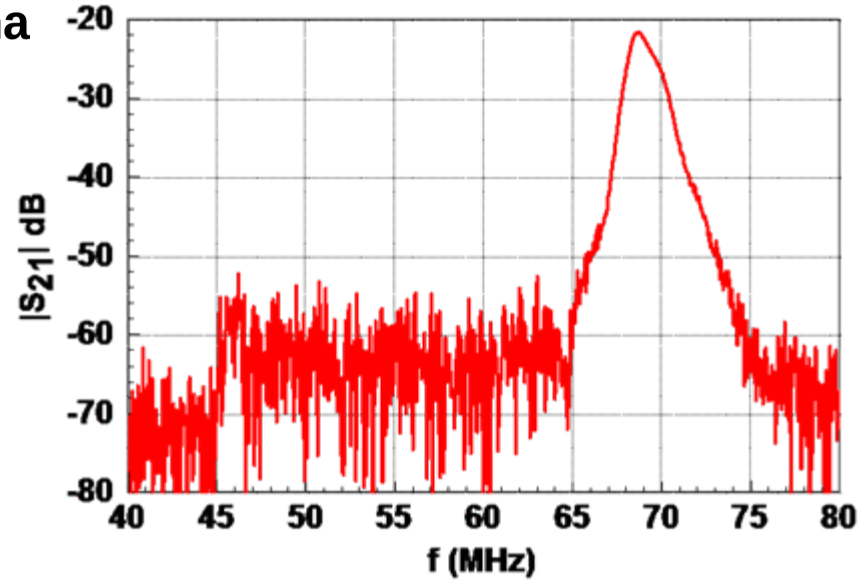
EIGER Simulation

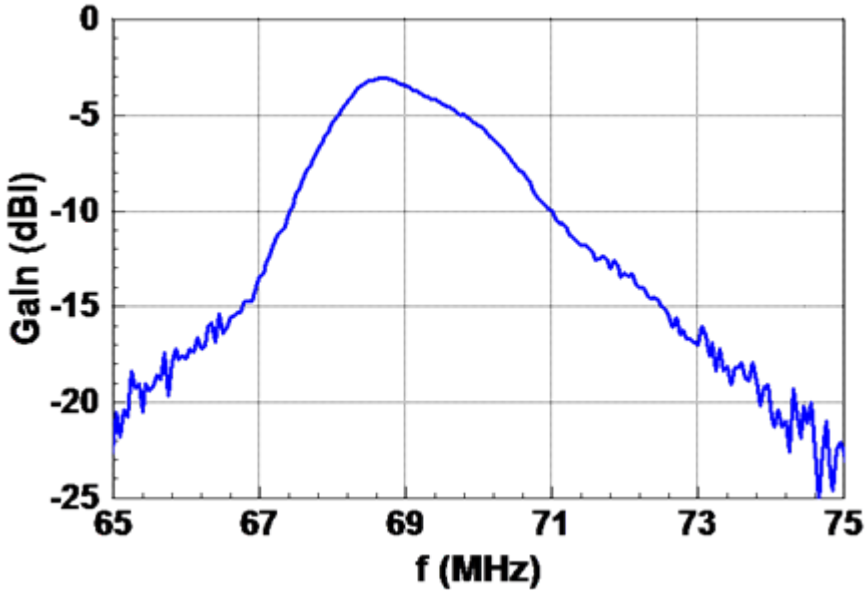
- Significant size reduction of the antenna
  - Half-wave dipole ($0.5\lambda_0$, 2.14m)
  - Miniaturized spiral-loaded slot antenna & ground plane ($0.07\lambda_0$ x $0.11\lambda_0$, 0.3m x 0.46m)
- Habitat walls are electrically conductive
  - Cannot use wire antenna directly against conducting wall
  - Integration of miniaturized HF antenna with habitat walls
    - E-textile antennas

HF Passive Sensor Antennas

- **Miniature Spiral-Loaded Slot Antenna**

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

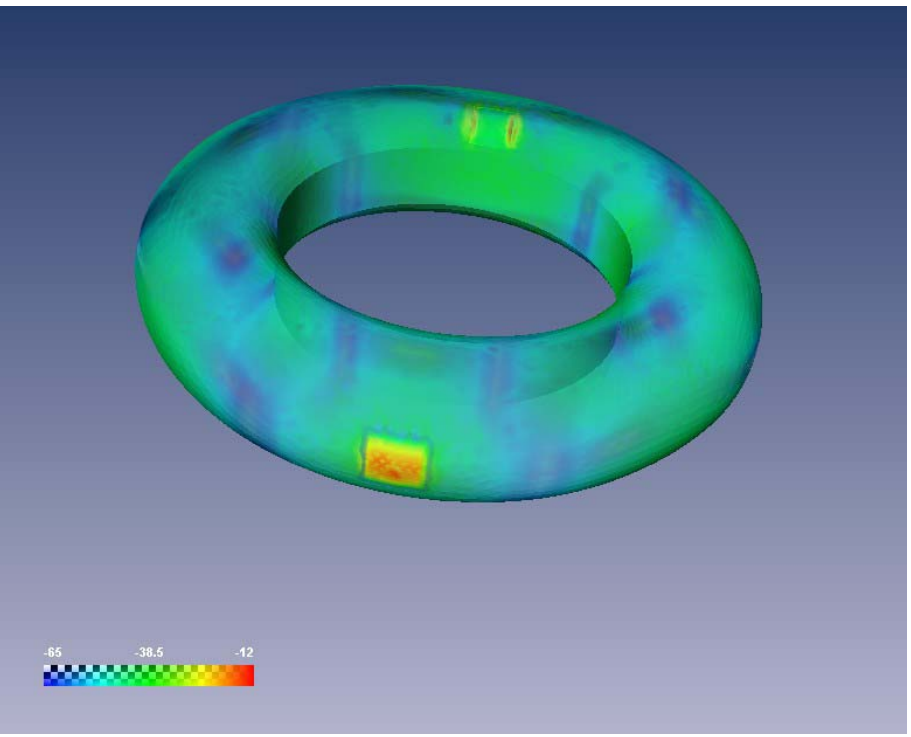


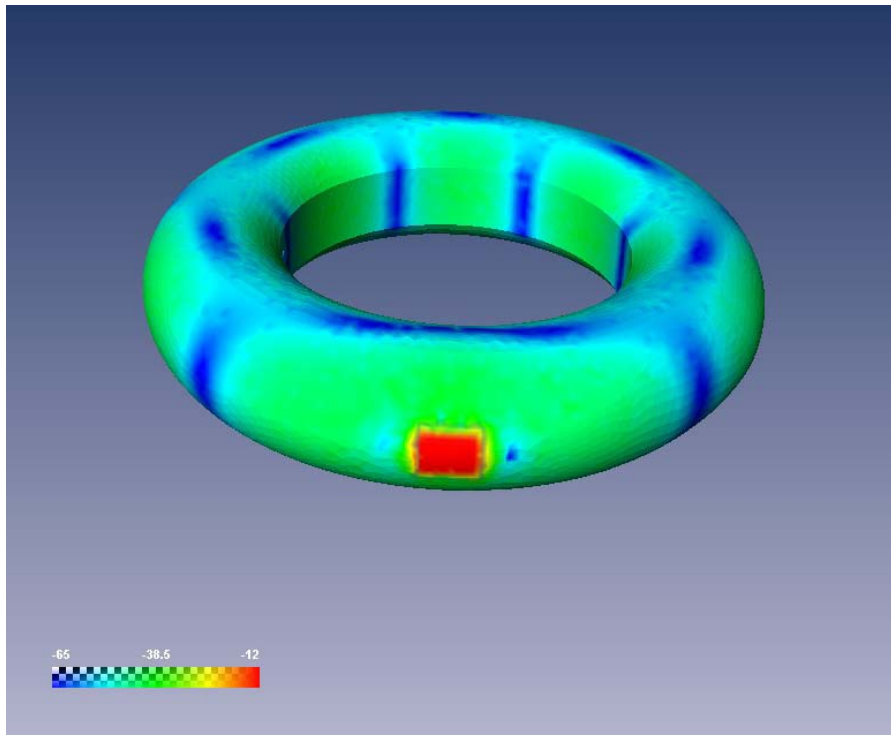


2.5% BW Gain > -5dBi

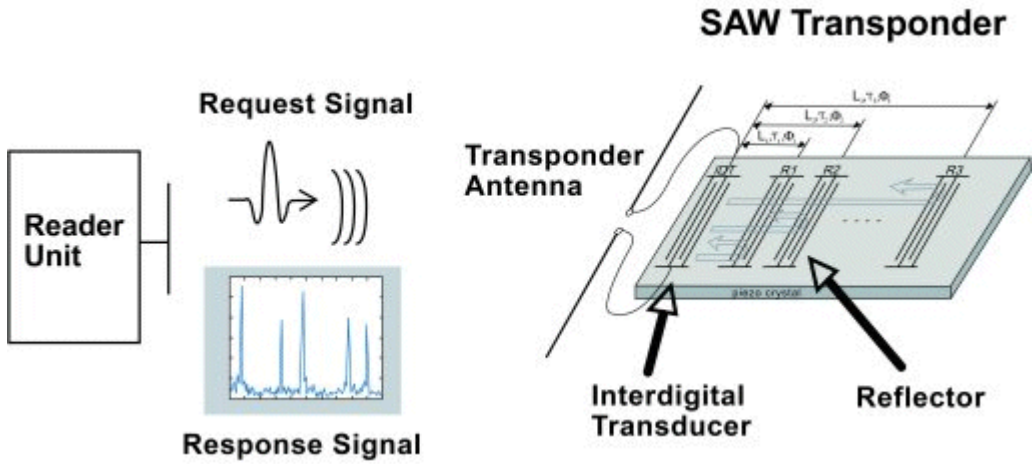
Habitat Module Interrogator-to-Tag Coupling

- Coupling between two 70MHz antennas
  - Received power levels at different locations in the mockup
  - Model effects of blockage with equipment in habitat module

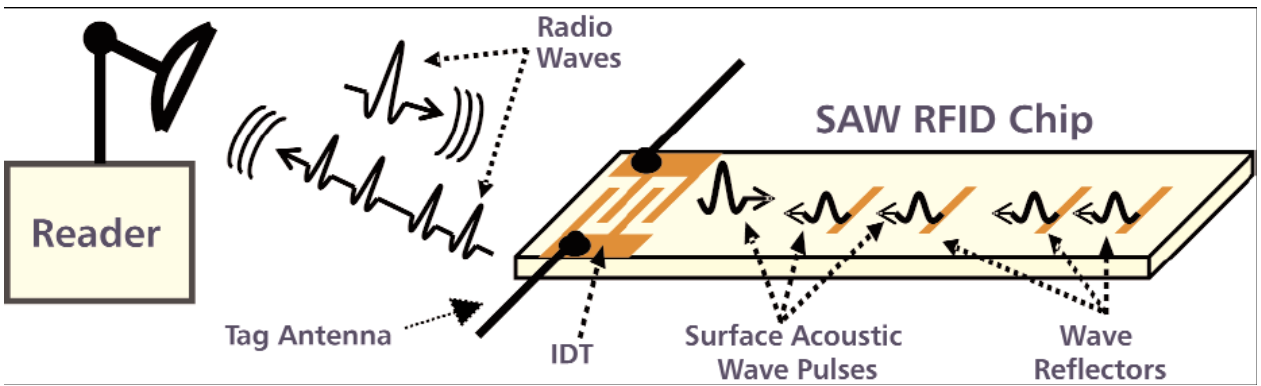




NASA Use of 2.4 ISM SAW-Based RFID



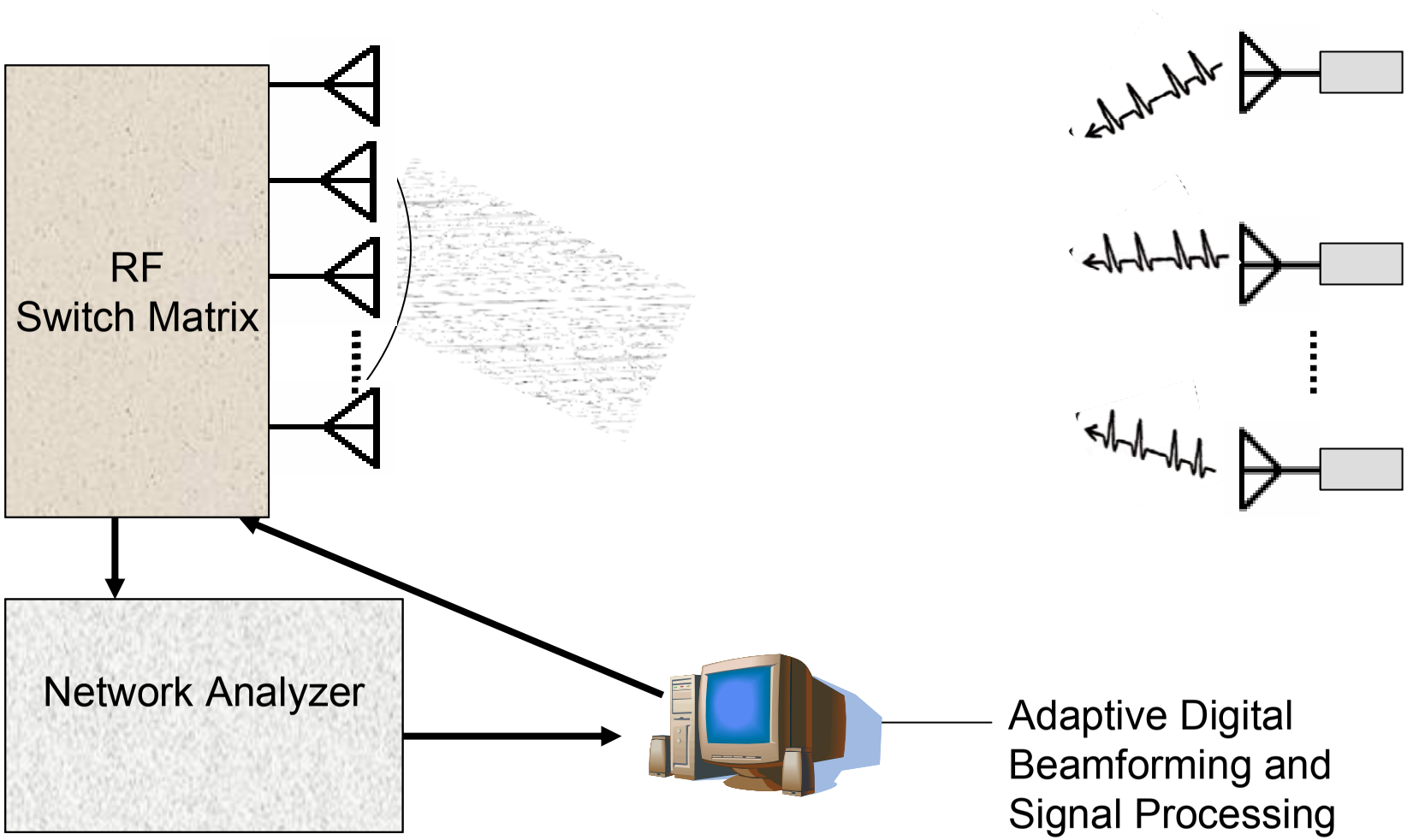
Courtesy AirGATE Technologies



Courtesy RFSAW, Inc.

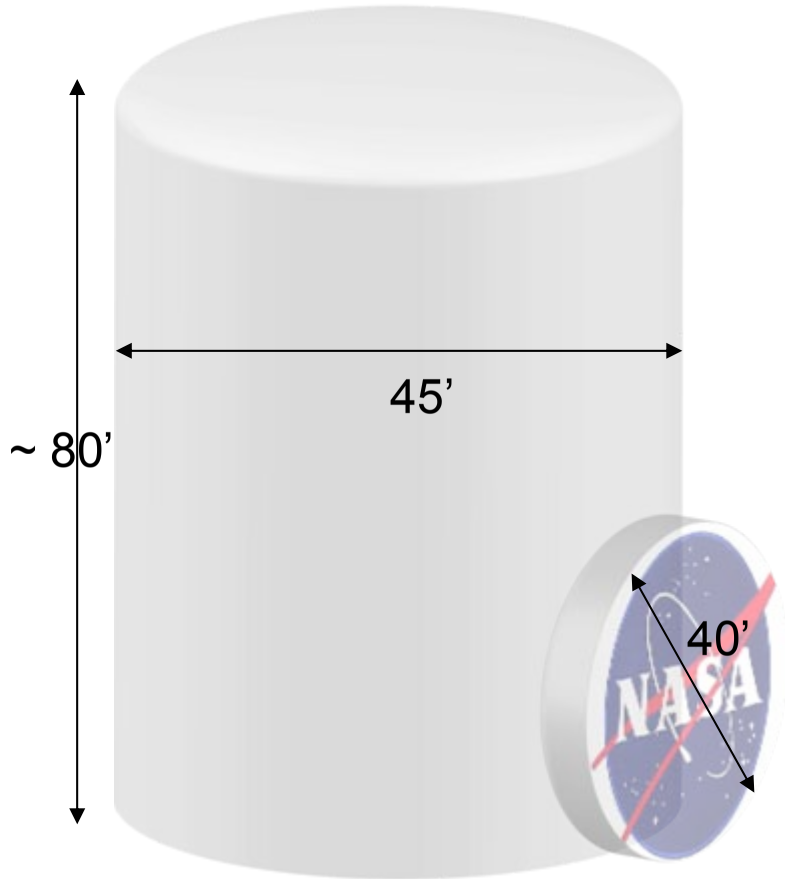
RF Collision Avoidance Methods

- Spatial diversity through adaptive digital beamforming



JSC Chamber A Passive, Wireless Sensors (CHAPS)

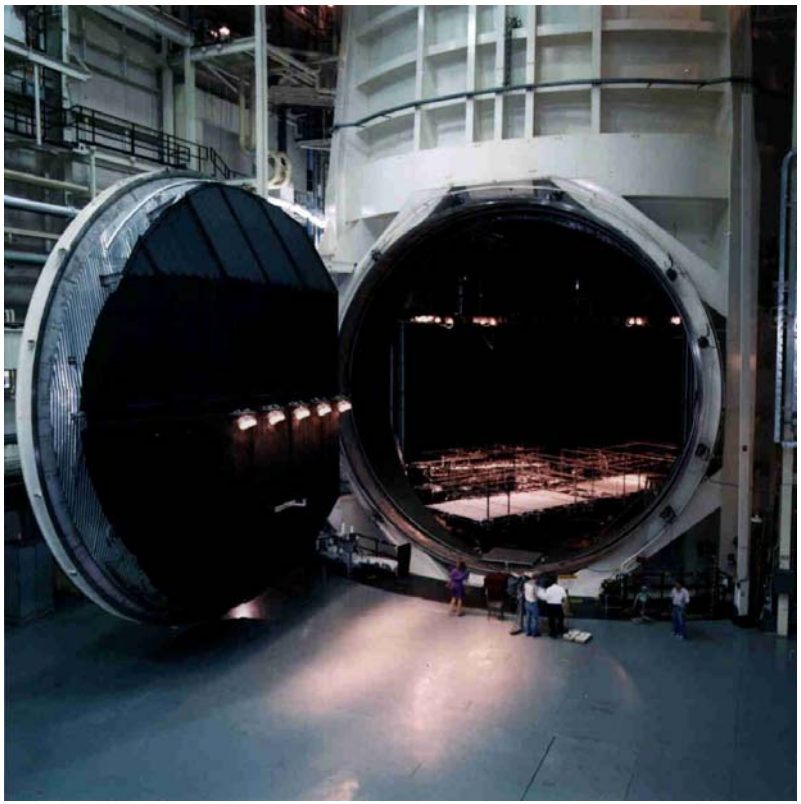
- Chamber A: Vacuum and Thermal Cycle Testing of Flight Hardware
- Objective: replace wired thermal and pressure sensors with wireless sensors
  - Reduces setup time between vehicle configuration changes
- Stage: feasibility assessment
- Thermal limit cold side: 20K
- Applications for vibration and acoustic facilities are also being explored



Approximate dimensions

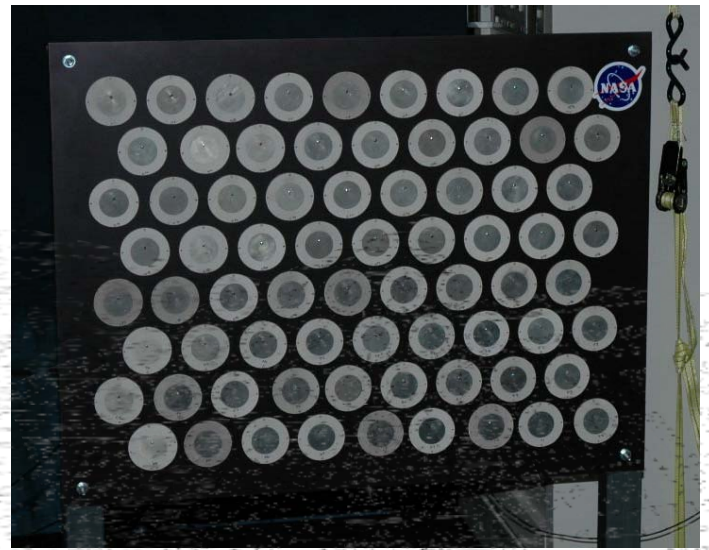
Environmental Facility Wireless Sensors

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



JSC Chamber A
(Vacuum & Thermal Cycle)

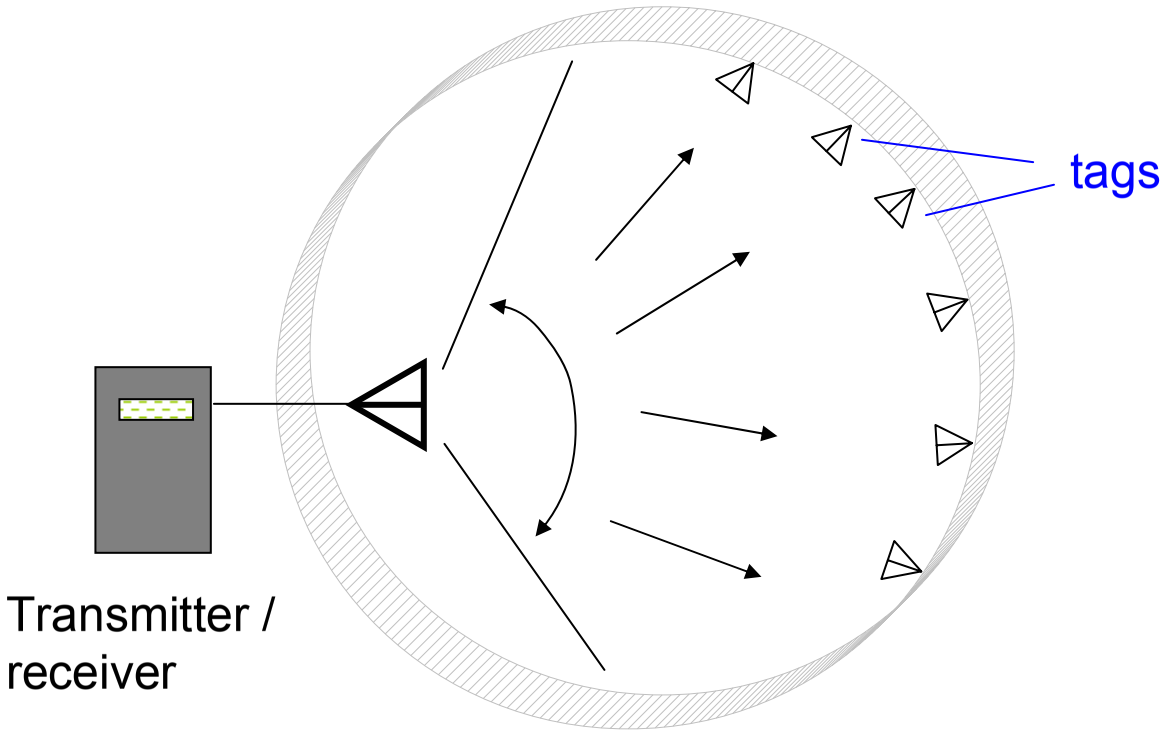
72-Element, S-Band, Adaptive, Digital Beamforming for Tag Interrogation



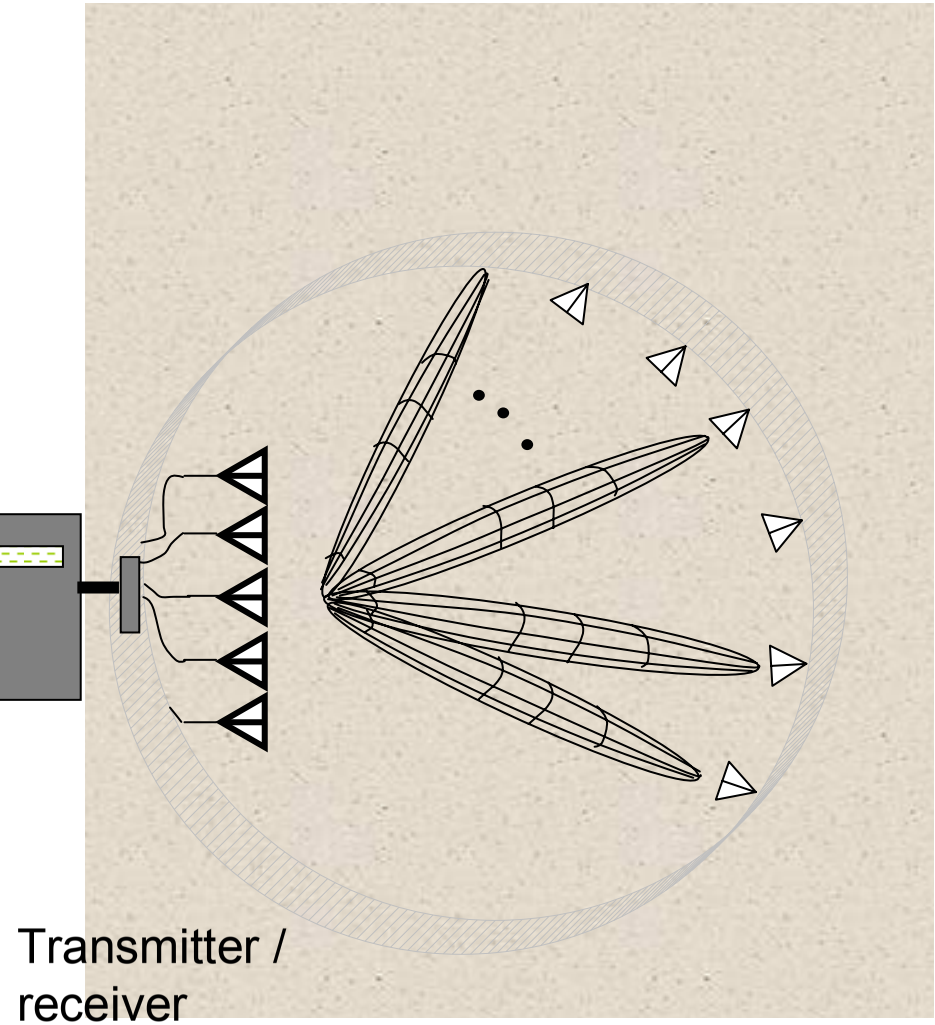
Antenna System Approach

- 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



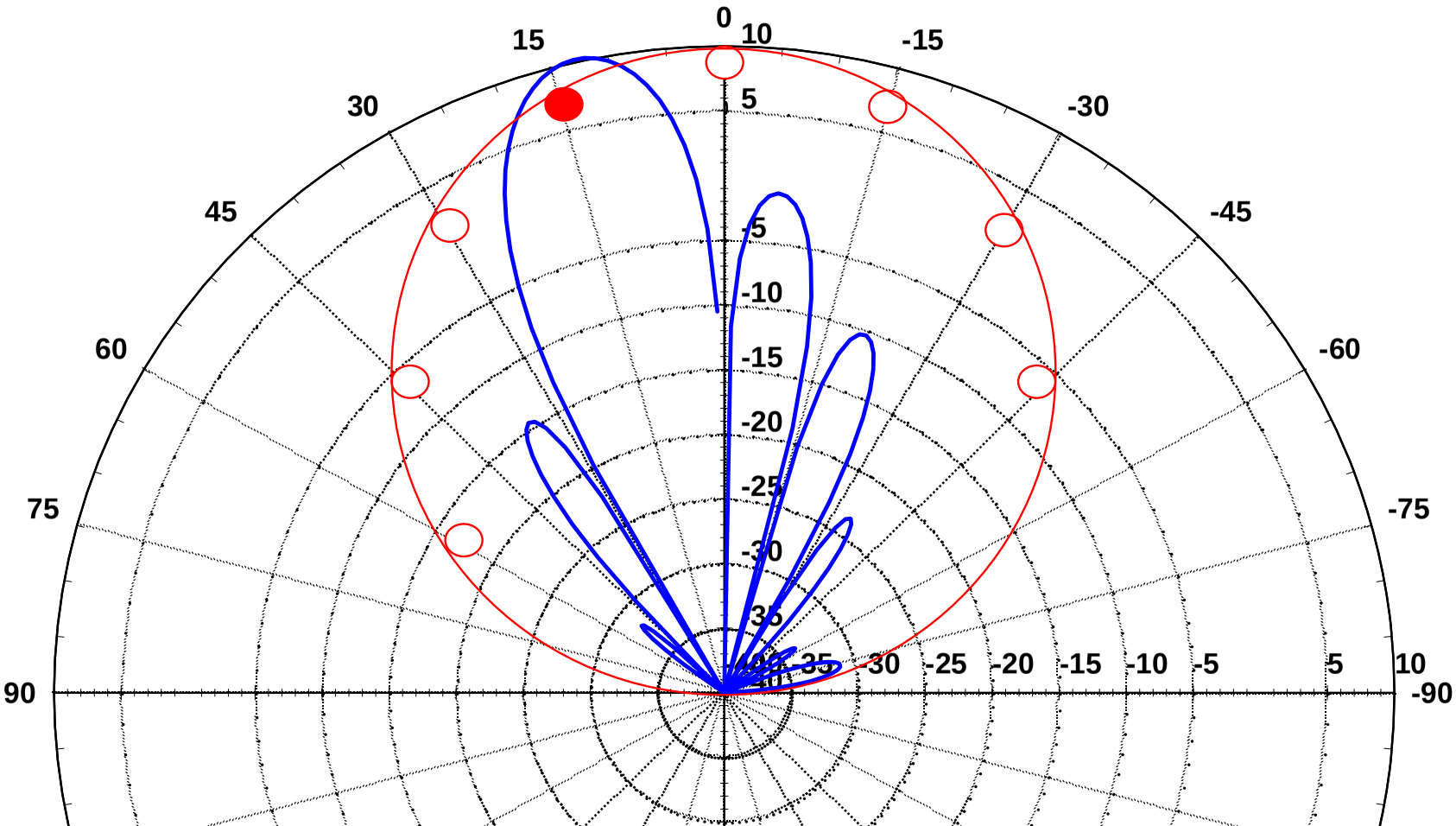
- Digital samples on each receive element
- Beams are formed digitally
  - number of simultaneous beams limited only by external processors
- All tags within transmit beam are read by multiple, simultaneous receive beams

Example of Spatial Diversity: Schelkunoff array

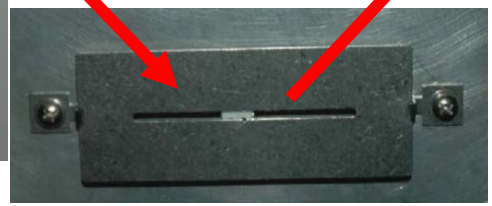
Chamber Simulation Tag 5

8 Element Schelkunoff Array

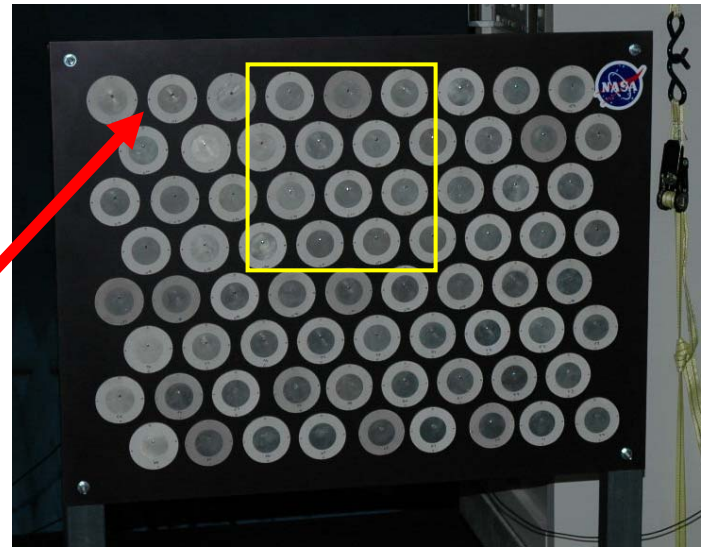
Patch width = 4.14 cm
Substrate thickness = .445cm
Element spacing: d = .62 λ

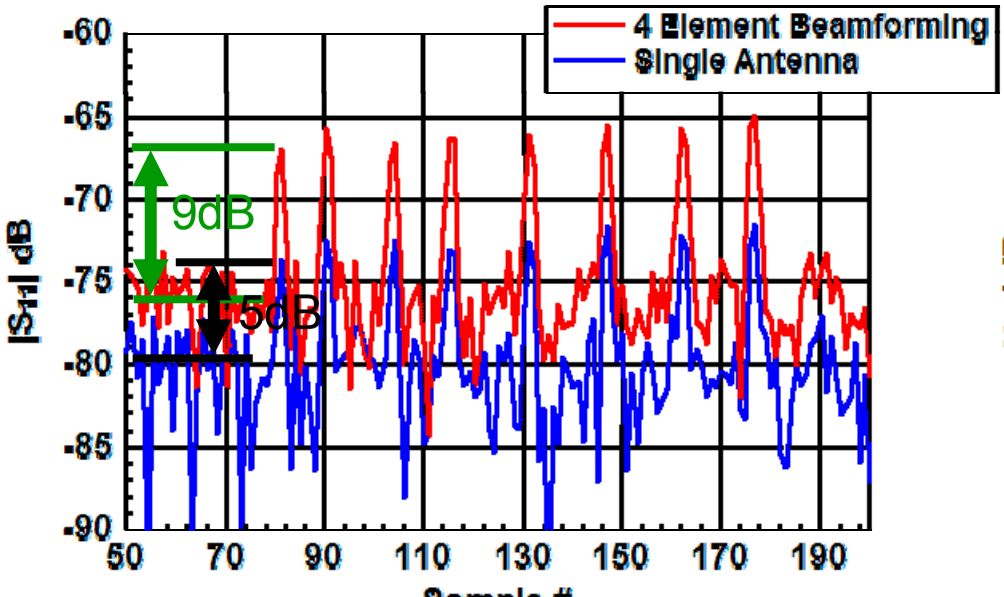


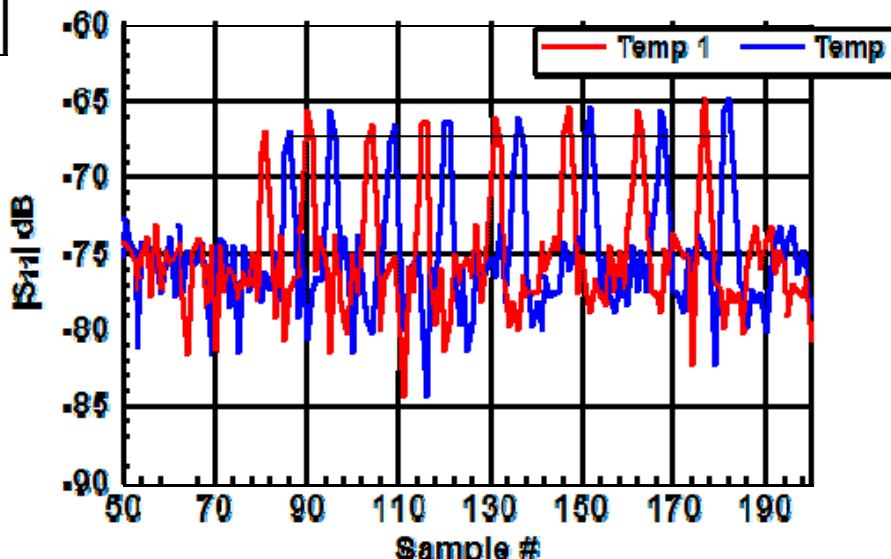
Beamforming and Temperature Sensor Demo



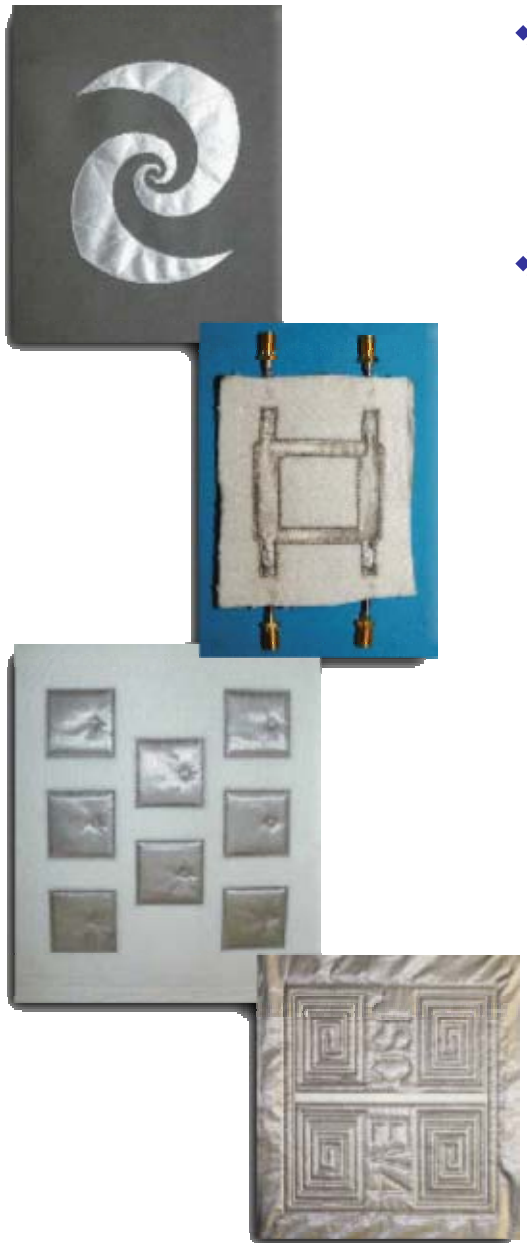
AirGATE Technologies /
CTR tag + slot antenna







E-Textiles for Wireless & RFID



- 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