National Aeronautics and Space Administration

Wireless Sensors Applications at Marshall Space Flight Center

Leo Fabisinski

MSFC Advanced Concepts

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MSFC Wireless Study Background

- Informal collaboration among various project teams
  - Wireless Strain Sensors
  - Wireless Network Studies
  - Wireless Sensor testing in ECLSS Group
- Wireless Technology Development Group
  - Response to request by Director of Engineering (Chris Singer)
  - Shawn Wallace and Delisa Wilkerson (Electronic Design Branch) organized group and invited interested parties
  - Request sent message that wireless technology needed study
- Questions about Scope and Direction
  - Individual efforts focused on very specific technology goals (e.g. mesh networks, wireless power transmission)
  - Past studies (e.g. CLV Avionics Task Report; 2006) had concluded that the technology was not mature enough for mission use at that time
  - Need for comprehensive understanding of the place for wireless technology in Marshall's Missions

Scope and Purpose of Study

Determine what Marshall Engineering can do in order to develop a capability to apply Wireless Sensor Technology to meet the mission needs of Marshall Space Flight Center.

Study Evaluation Process

1) Assess the current state of the art in WST as it applies to MSFC missions.
2) Identify WST Application Areas best suited to MSFC missions and evaluate the top-level requirements for applying the technology in those areas
3) Evaluate the major remaining challenges to those applications and provide viable options for meeting those challenges
4) Survey current MSFC research efforts and capabilities
5) Recommend directions for center investment and opportunities for collaboration with other NASA centers

What is the State of the Art?

What Do We Need?

What Doesn’t Work Yet?

What are We Working On Now?

What Else Do We Need to Do?

Wireless Sensors

Landers & Ascent Vehicles (Sample Return Missions)

- **Hazard Avoidance Maneuvering**
  - Target tracking, object identification, and health monitoring for improved reliability
  - Multi-sensor data fusion – wireless data acquisition systems
  - Terrain classification
- **Vehicle Management Systems**
  - Extreme operating conditions: vibrational loading, thermal and pressure systems
  - Cryogenic Fluid Management
  - Turbo Pump Assemblies
  - Decentralized (sensor located) and centralized processing
- **ISRU (Sample Return)**
  - Object Recognition and Manipulation
  - Manipulators for drilling and sample handling
  - Relative Navigation Sensor and Guidance System

Cis-Lunar Habitat

- **Human Habitat**
  - Autonomous Logistics Management, including Inventory Management and General Spacecraft Communication
  - Integrated Habitat – autonomous monitoring, automated failure isolation and recovery, and situational awareness to the crew
  - Electronic Textiles and Physiological Sensors, e.g. Radiation Dosimeter, Crew Member Location
- **Vehicle Management & Health Monitoring Systems**
  - Energy Harvesting/ Low Power / Low Voltage on demand V-band Transceivers
  - HVAC, ECLSS, Lighting Monitoring, Docking, Rendezvous
- **Challenges**
  - Overcoming Electro-Magnetic Interference in Metallic Environments
  - Multimodal, multi-domain signal processing optimization for cross-layer

Mars Concepts

- **Situational Awareness and Communications**
  - Multiplexed streams of voice, video and data over a communications channel including EVA, collaborating planetary surface components (e.g. rovers, landers) and feedback mechanisms
  - Information Filtering of multi-sensor data fusion
  - Software defined communications and adaptive networks
- **Sensor Node Architecture**
  - Smart sensors/transducers & data representation for intelligent architecture
  - Overcome conventional, strict protocol stacks to adaptive networks capable to handle changing conditions to efficiently utilize available frequency spectrums and energy resources
  - Evolve from circuit-switched to packet based infrastructure
  - Small Sat Networks

Cross Cutting
Autonomous Operations
Assembly, Integration and Test
Extreme Environments

WIRELESS SENSOR APPLICATIONS

We used a structured method for selecting the Wireless Sensor Applications that were of the most value to the Center. These applications are the basis for further consideration in the study.

Application Selection

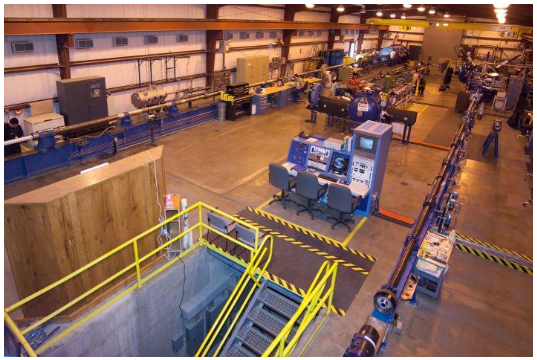
- Potential Benefit vs State-Of-Art
  - Lower Mass
  - Lower Cost
  - Lower Risk
  - Provide enhanced capability
- Relevance to MSFC Missions
  - Alignment to MSFC priorities (Tiers)
  - Benefit to current ED development efforts
- Leverage of MSFC Capabilities
  - Personnel and facilities available at MSFC
  - Experience base at MSFC in Application Area
- Stage of Maturity (TRL 4-7)
- Cost to Develop

Application Selection

Application	Benefit	Alignment	Leverage	Maturity	Cost	Total
Testing	8	10	8	5	10	41
On-Spacecraft Science	4	4	8	4	10	30
Robotic effector (Incl Rovers)	7	2	2	8	7	26
Automated Docking	5	5	9	9	6	34
Vehicle Health & Performance Monitoring	8	9	7	8	8	40
Surface Science	8	5	6	4	5	28
Habitat	10	9	7	9	9	44
Inner-Vessel	10	9	9	6	6	40
Tracking and Proximity Ops	9	7	5	5	7	33

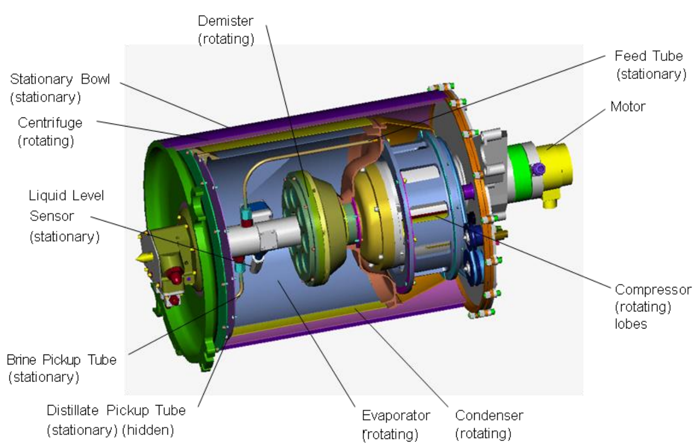
High Value Application Areas

Testing

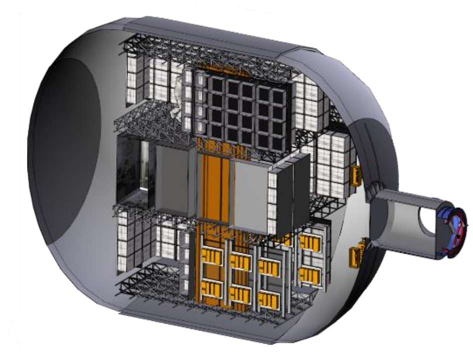


Vehicle Health Monitoring

Inner-Vessel



Habitation



Testing

- Wireless sensors may be used in the testing lab to allow test engineers to re-instrument test samples quickly between tests on the basis of intermediate test results. Both the configuration and number of sensors may be changed dynamically with little effort. Advantages include:
  - Lower test setup costs
  - Greater flexibility in instrumenting samples and thus better quality test data
  - Ability to easily replace sensors when their outputs are questionable
- Top-Level Requirements
  - Ability to sample and collect up to 200 sensors simultaneously.
  - Accuracy at least as good as that currently available in each lab
  - Environments - shirt sleeve / test extremes (vacuum, temp, pressure)
- Specific Applications at MSFC
  - Static Testing Facility
  - Mechanical Testing Facility
  - ECLSS Testing

Vehicle Health and Monitoring

- Wireless Sensors may be used to perform the same health and monitoring functions for vehicles on pad and in flight as the wired sensors do in current craft. Advantages include:
  - Reduction in cable mass and volume. Simpler structures with fewer conduits and brackets.
  - Flexibility to locate sensors in places inaccessible to wired sensors (e.g. on outbound structures like wing leading edges).
- Top-Level Requirements
  - Autonomous operation at point of acquisition (must maintain power, data connection) for mission duration.
  - Accuracy at least as good as that available on existing vehicles
  - Must withstand space environment, vehicle environments.
- Specific Applications at Marshall
  - Avionics upgrades to SLS Core and Upper Stages
  - Exploration Landers

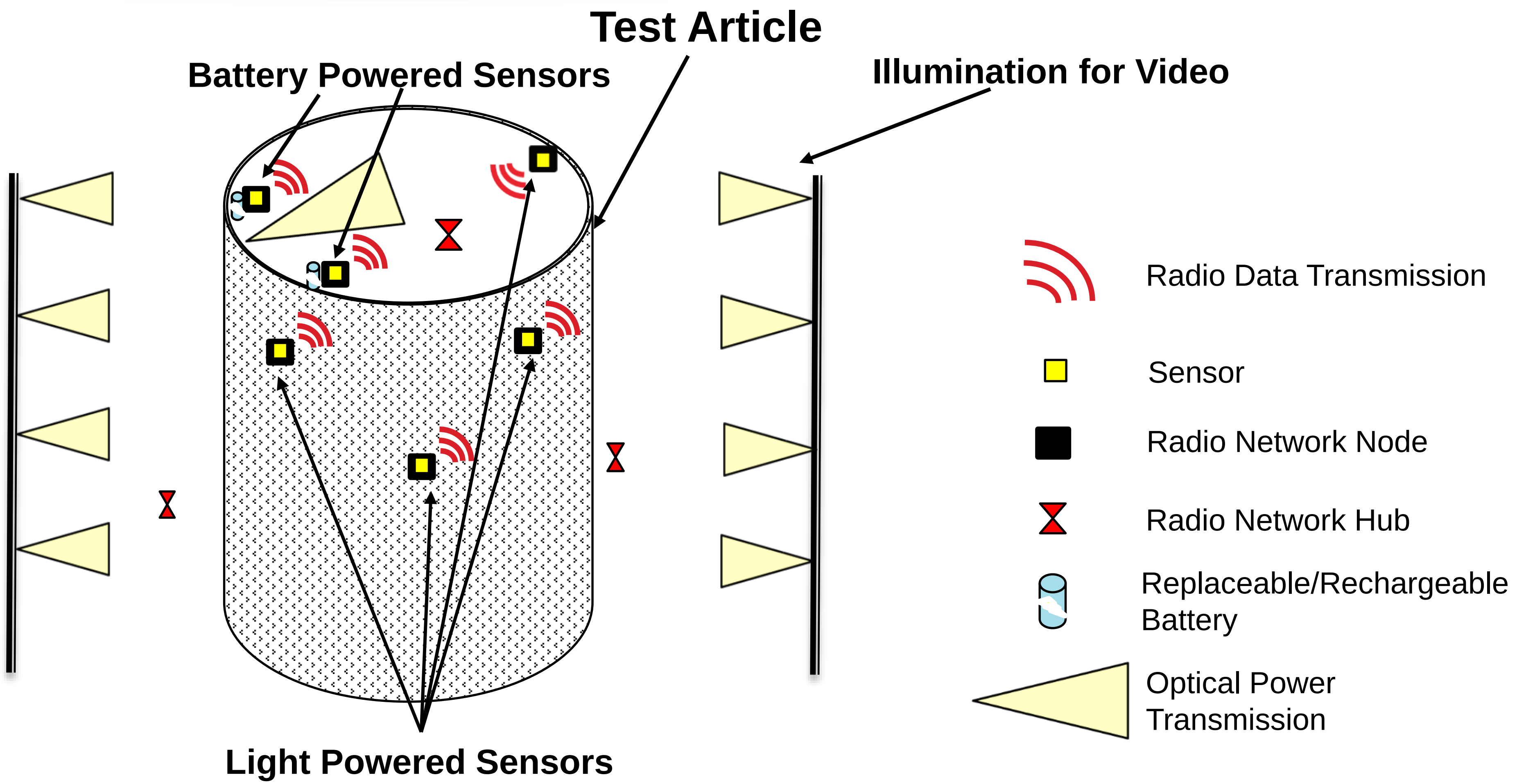
Inner-Vessel Sensors

- Wireless Sensors may be located inside sealed vessels (e.g. tanks) and on moving machinery (e.g. turbine blades) to provide data on conditions there and transmit that data through the vessel walls for relay. Advantages include:
  - Elimination of feed-through penetrations and fixtures for power and data. This decreases the cost of the vessels and decreases the risk of failure.
  - Allows designer to provide more and better monitoring
- Top-Level Requirements
  - Autonomous operation at point of acquisition (must maintain power, data connection) for mission duration through vessel walls.
  - Accuracy at least as good as that available on existing vehicles
  - Must withstand space environment, vehicle environments
- Specific Applications
  - Sensors on interior of propellant tanks
  - Sensors inside assembly fluid enclosures (e.g. ECLSS, Engines)

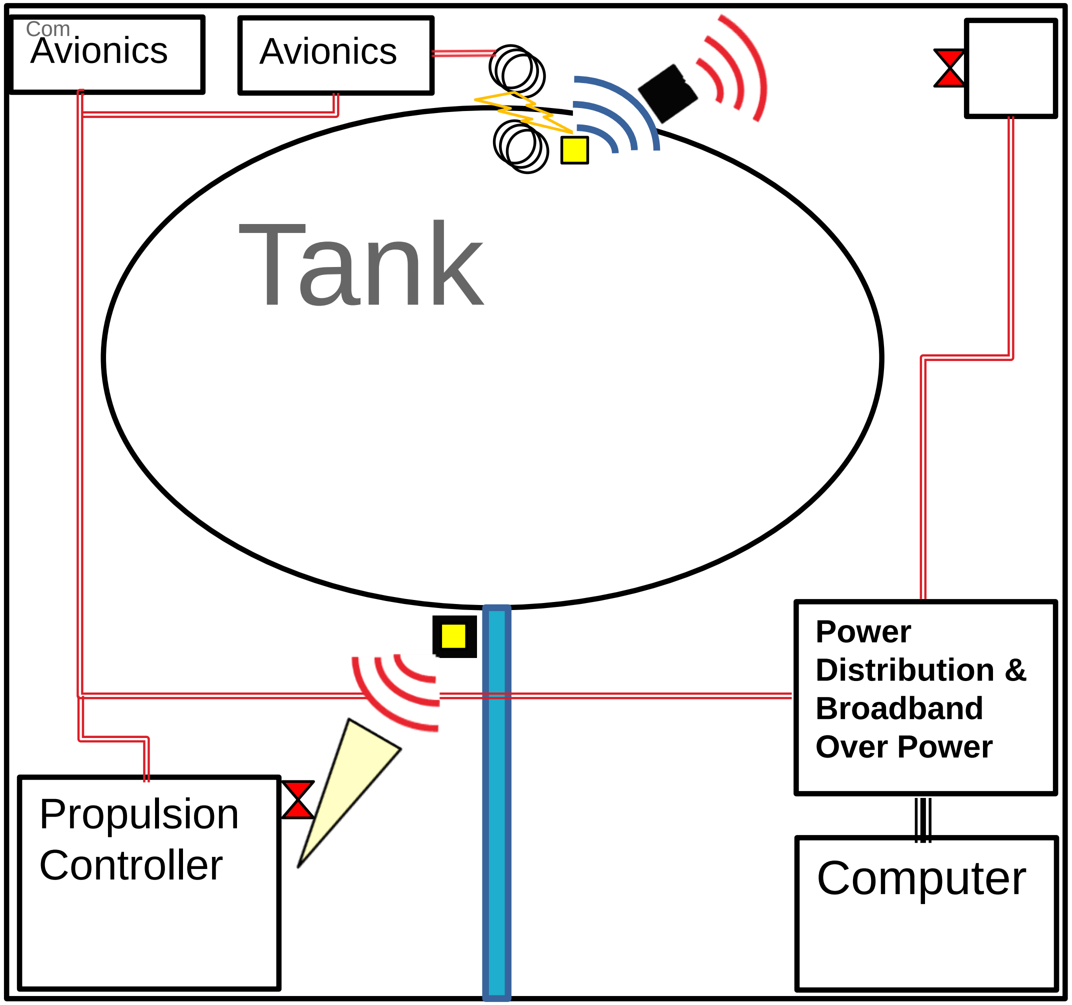
Habitation

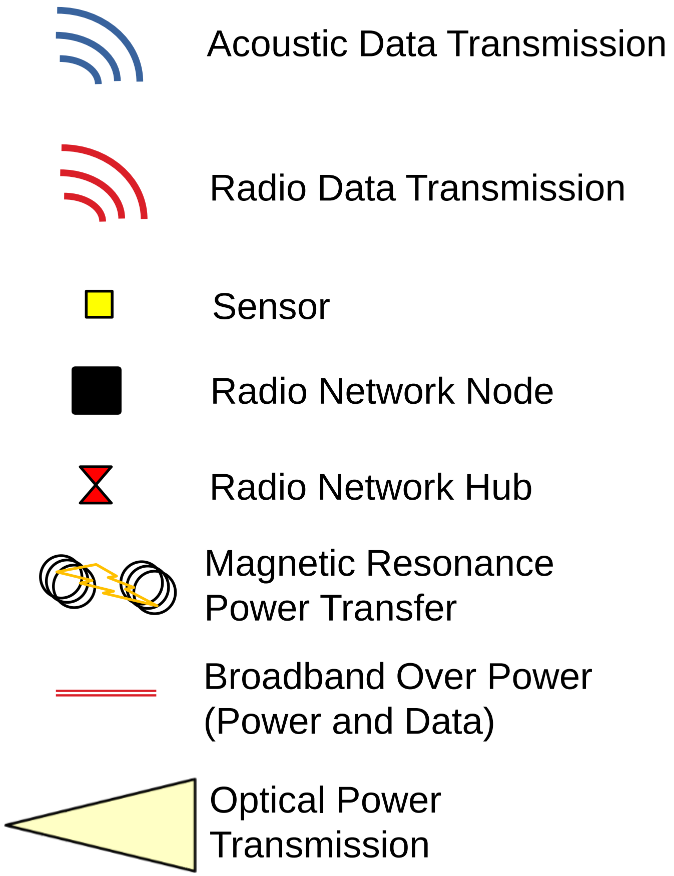
- Moveable environmental sensors (Temp, CO_2, O_2, etc) may be placed wherever needed without connection or software configuration. RFID Tags may be included with payloads and interrogated to provide location information. Advantages include:
  - Automated inventory control and location.
  - Flexibility to locate sensors wherever needed almost immediately.
  - Sensors may be built into equipment sent to habitat and accessed wirelessly.
- Top-Level Requirements
  - Autonomous operation at point of acquisition (must maintain power, data connection) for mission duration.
  - Must withstand habitat environment – radiation and microgravity.
- Specific Applications at Marshall
  - Deep Space Habitats

Test Stand Architecture (See Notes for Description)

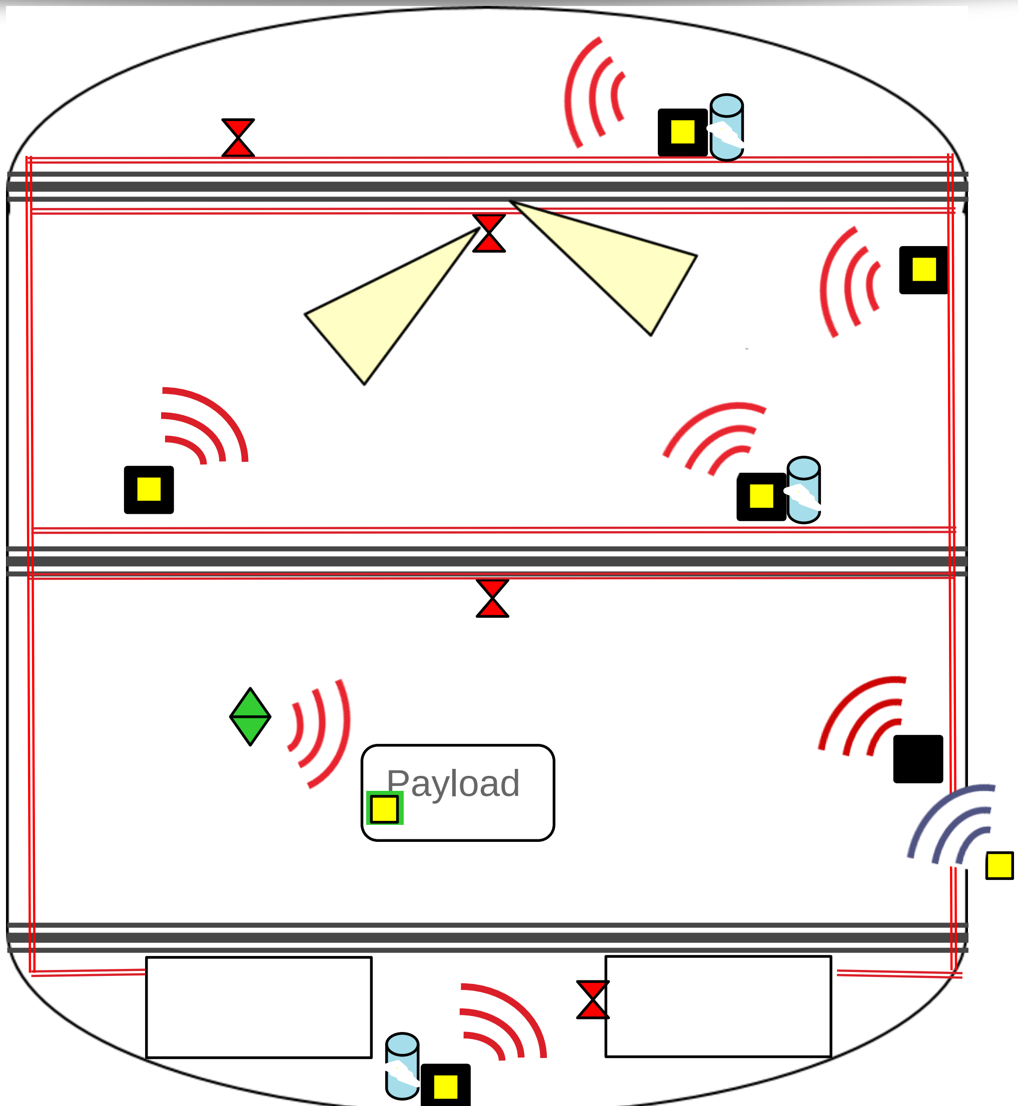


Vehicle Architecture (See Notes For Description)





Habitat Architecture (See Notes For Description)



- Acoustic Data Transmission
- Radio Data Transmission
- Sensor
- Radio Network Node
- Radio Network Hub
- RFID Interrogator (Power & Data)
- RFID Tag
- Replaceable/Rechargeable Battery
- Broadband Over Power (Power and Data)
- Optical Power Transmission

Observations

- Most of the sensors that we need are available COTS or may be easily provided by ES63. It is chiefly the wireless communications technology that requires attention.
- There are several wireless networks suitable for our applications and we have access to them. All of these can work with any point to point communications system.
  - ZIGBEE – open-source implementations are available. The protocol seems to work very well in low interference environments.
  - ISA100.11a – Intelligent spread-spectrum radio layer: resistant to interference.
- It is unlikely that wireless sensors will ever completely replace their wired counterparts, but a significant number of applications could find their way into NASA's missions in the next 10 years. **In general, the trend is to realize avionics and computing systems as a large number of stand-alone, cooperating, distributed units.**
- Most of the technological challenges to Wireless Sensor application are well characterized and have a variety of promising avenues for solution. There are no major 'show-stopping' obstacles.

Observations

- Basic conceptual design studies in applying wireless sensors to typical missions would be helpful at this point in developing further requirements and assessing costs and benefits of wireless sensors in each possible role.
- The total mass savings from widespread use of wireless sensors in our architectures is modest – in general < 100kg / Element (stage, lander, habitat, etc). The major benefits are integration simplicity, flexibility and enhanced capability. These will likely yield significant cost savings.
- Wireless sensors are already in use on ISS, and Space Habitats will likely be early adopters of future technology. The same may be said for test applications.
- There are significant collateral benefits to developing this technology, including:
  - More robust low-powered networks for home-based applications
  - Better health monitoring for automobiles, HVAC, and other large, long-life machines.
  - A generalized methodology for cooperative computing