



**Robust Large-Scale Distributed Wireless Communication for Aircraft  
Integrated Vehicle Health Management**

**ICNS Conference**

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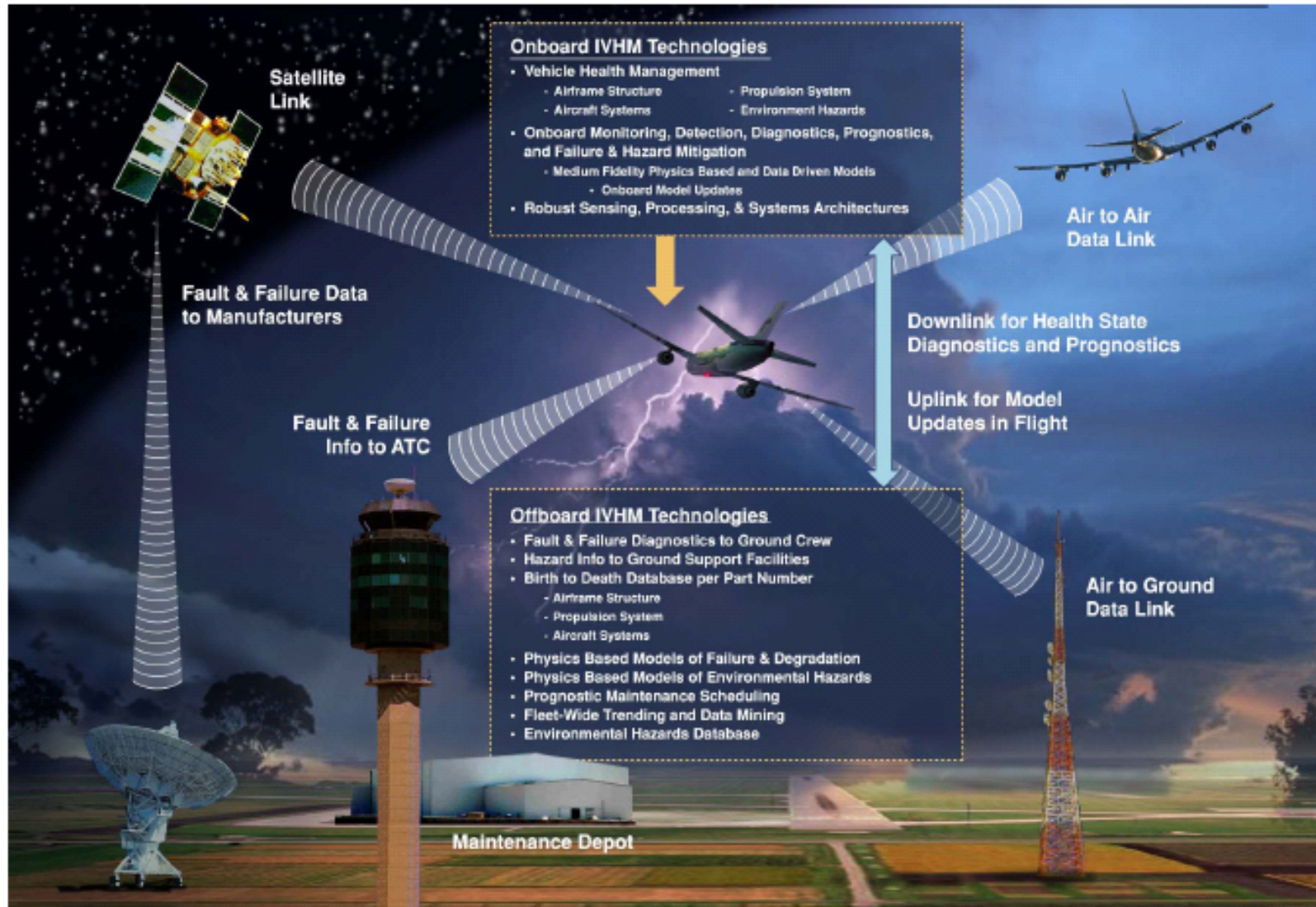
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# IVHM Future Concept of Operations

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- Provide continuous on-board situational awareness of vehicle health state for use by the flight crew, ground crew, and maintenance depot
- Reduce system and component failures as causal and contributing factors in aircraft accidents and incidents



# IVHM Communication

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## Needs:

- Connection of all sensing and processing elements
  - Airborne and Ground Based
- Operation throughout airframe environment
  - Harsh Environments (Temperature, Vibration, EMI, etc.)
  - Constrained Spaces (enclosed metal/composite structures)
- Robust
  - Must function during off-nominal conditions

## Response:

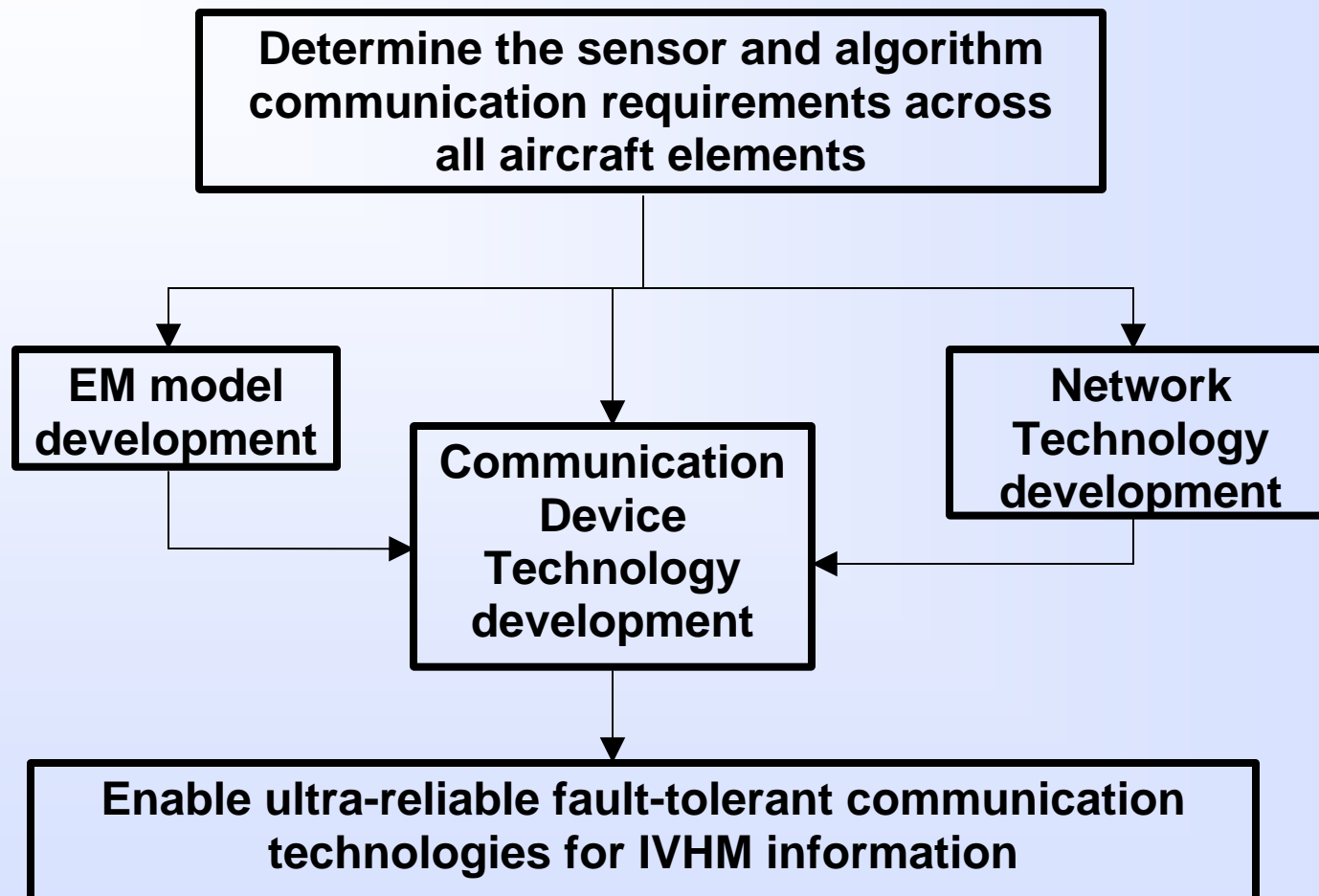
- Wireless Communication System Technology advancements to enable sensor placement beyond the reach/practicality of wired and optical interconnects
  - **Sensor Architecture Requirements** to understand the scale of future sensor and processing elements
  - **EM Modeling** leading to frequency selection, and antenna development
  - **Network Technologies** for robust data flow
  - **Transceiver Device Development** to allow integration of sensing, processing, energy harvesting, transceiver, and antenna components.



# Wireless Communication Overview

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# Sensor System Architecture Requirements

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Determine overall communications requirements for IVHM data and information for both onboard and offboard a commercial transport aircraft

- Determine current sensor locations, data precision, and data rates for a typical commercial transport aircraft
  - Using a 757-200 aircraft as the baseline for legacy aircraft
- Determine future sensor locations, data precision, and data rates from sensor and algorithm developers
- Determine communications necessary to sensors, for calibration, data rate “throttling,” etc.
- Make tradeoffs considering: data rates, network architectures, transmit power, and data processing within the sensor
- Determine offboard communications requirements for transmission of IVHM data both to and from an aircraft



# Sensor System Architecture Requirements

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Developing three documents:

Onboard Communications Requirements

- In Final Review

Onboard Wireless Communication Architectures

Offboard Communication Requirements



# Sensor Category Examples

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## **Structural Health Monitoring**

Sensors scan for small cracks in the airframe, fatigue damage, hidden cracks in hard-to-reach locations, disbanded joints, erosion, and corrosion.

## **Ice Monitoring/Detection**

Smart ice-management sensors detect the effect of accumulated ice on the performance and handling qualities of an aircraft.

## **Fire Detection**

Fire sensors monitor the chemical footprint indicative of a fire including carbon monoxide, oxygen depletion, and carbon dioxide.

## **Gas Presence**

Sensors that are used to detect the presence of emissions, such as hydrocarbons, oxygen, and nitrogen oxide.

## **Pressure Sensing**

Sensors that are used to detect changes in pressure.

## **Propulsion**

Sensors used to measure the performance and health of the engine

## **EMI Detection**

Detection of lightening strikes and EMI events from intentional/unintentional radiators

## **Aircraft Systems Temperature Sensing**

Detection of temperature abnormalities in aircraft systems, including brakes, electrical components/avionics, and mechanical systems.



# RF Modeling/Frequency Selection

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- Modeling of engine environment and other confined areas (ex. airfoil sections) in order to determine a set of candidate frequency bands, considering the propagation environment and EMI encountered within the aircraft.
- These candidate frequency bands will be matched against current frequency allocations and RTCA emission limitations to narrow the candidate frequencies to a set of design frequencies.

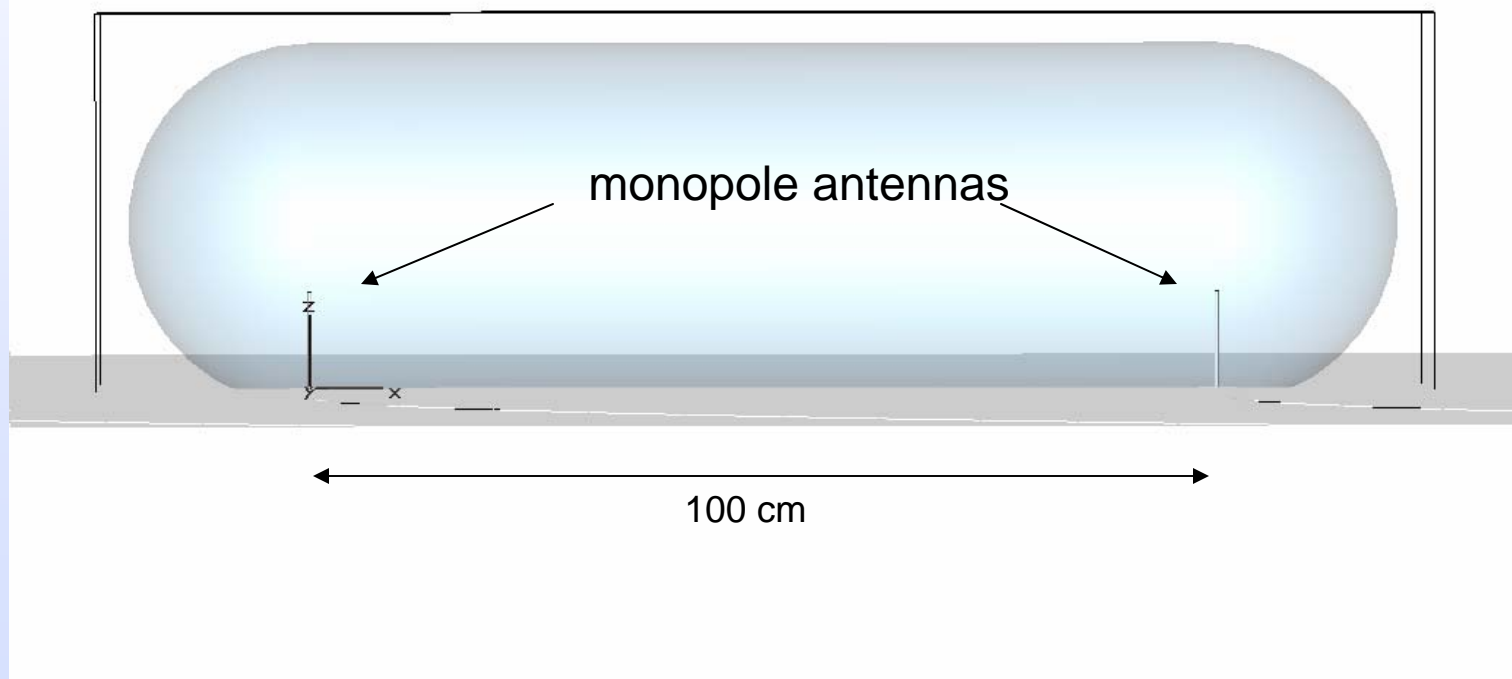


# Coupled monopole antennas, in cylindrical metal cavity

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- Monopole length = 10.6 cm (resonant at 2.0 GHz)
- Distance between antennas = 100 cm
- Cylindrical metal enclosure, radius = 20 cm
- Interior of enclosure is air

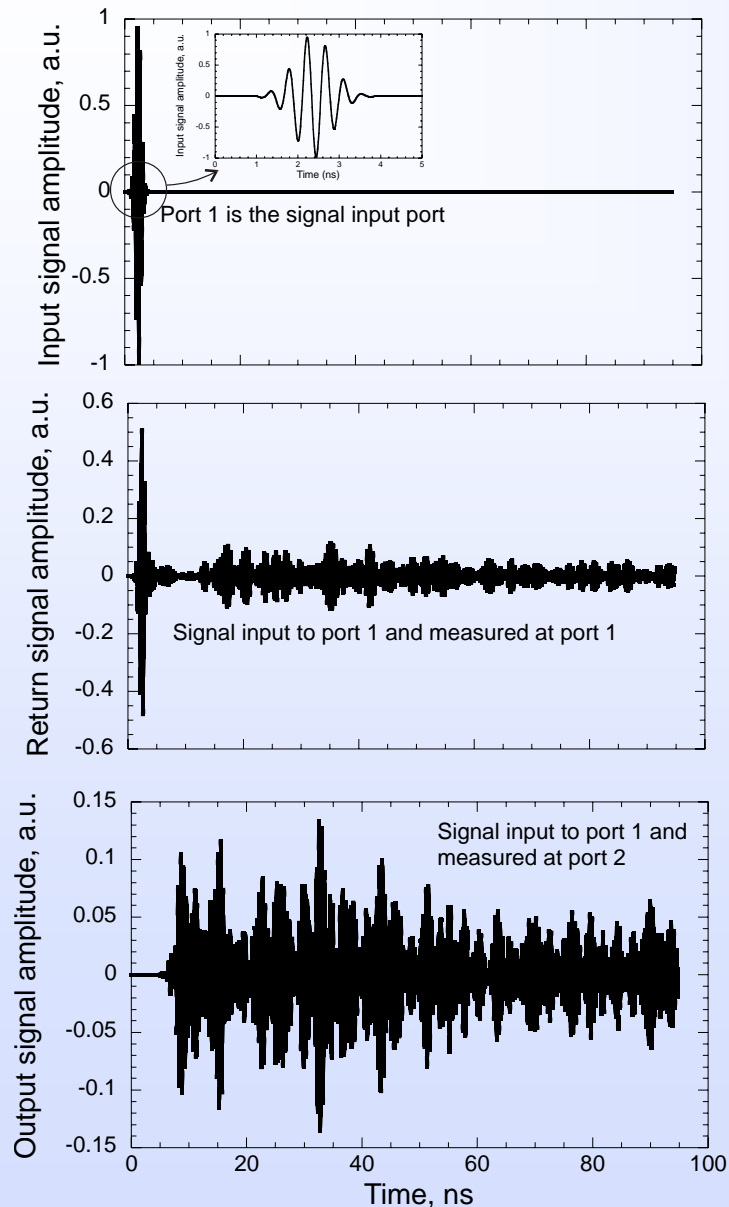




# Coupled monopole antennas, in cylindrical metal cavity

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- Simulation performed using Microwave Office's transient solver.
- Gaussian input signal, with frequency components covering the 1.5 – 3.0 GHz range.
- Reverberations clearly present in the port 1 and port 2 received signal spectra. These are attributed to reflections from the metallic walls of the cavity.



# Simulation Validation

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Validation of RF simulations will be conducted on a wing from a Navy S3 aircraft, located at NASA GRC.



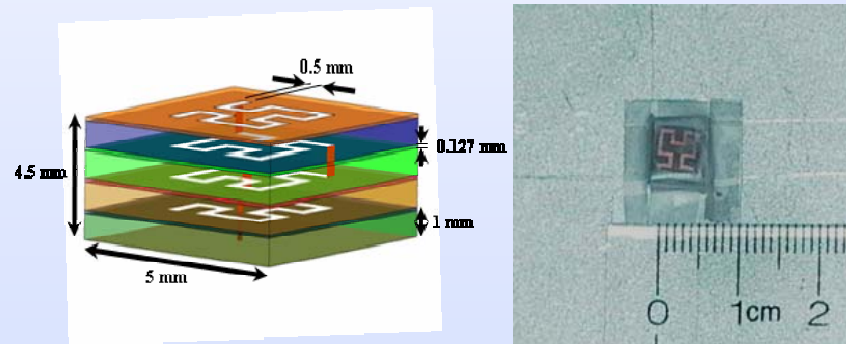


# Onboard Antenna Development

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Given the design size limitation for the embedded devices (less than 1 in<sup>3</sup>), antenna models/designs will be developed, as necessary, considering the design frequencies.



Minaturized ( $\lambda/30$ ) Antennas



# RF Spectrum Partners

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No dedicated aviation spectrum for wireless sensors is a major impediment for future deployment of wireless devices.

- This issue was raised by many airframe developers, equipment providers, and government representatives at CANEUS “Fly-by-Wireless” workshop, held March 2007.
- We are currently working within two industry led working groups formed during a “Dedicated Aviation Spectra Workshop”, held October 2007.
  - The EM modeling and frequency selection results from IVHM will be used as the technical basis for proceeding toward obtaining dedicated aviation spectrum at the World Radio Conference.



# Network Protocol Technologies

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Reduce link failure detection time to less than 500ms and reduce overall network convergence time to less than 1sec.

These design metrics are at least a 10-fold decrease from current detection and convergence times, which enables continued IVHM diagnostic and prognostic sensor based calculations during off-nominal conditions.

Current wireless network and ad-hoc technologies were designed for and assume open-air propagation, and will require parameter adjustments or protocol modifications to function in constrained environments.



# Network Protocol Technologies

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Develop network technologies/protocols to allow sensor data to be routed around wireless link problems, while maintaining data integrity.

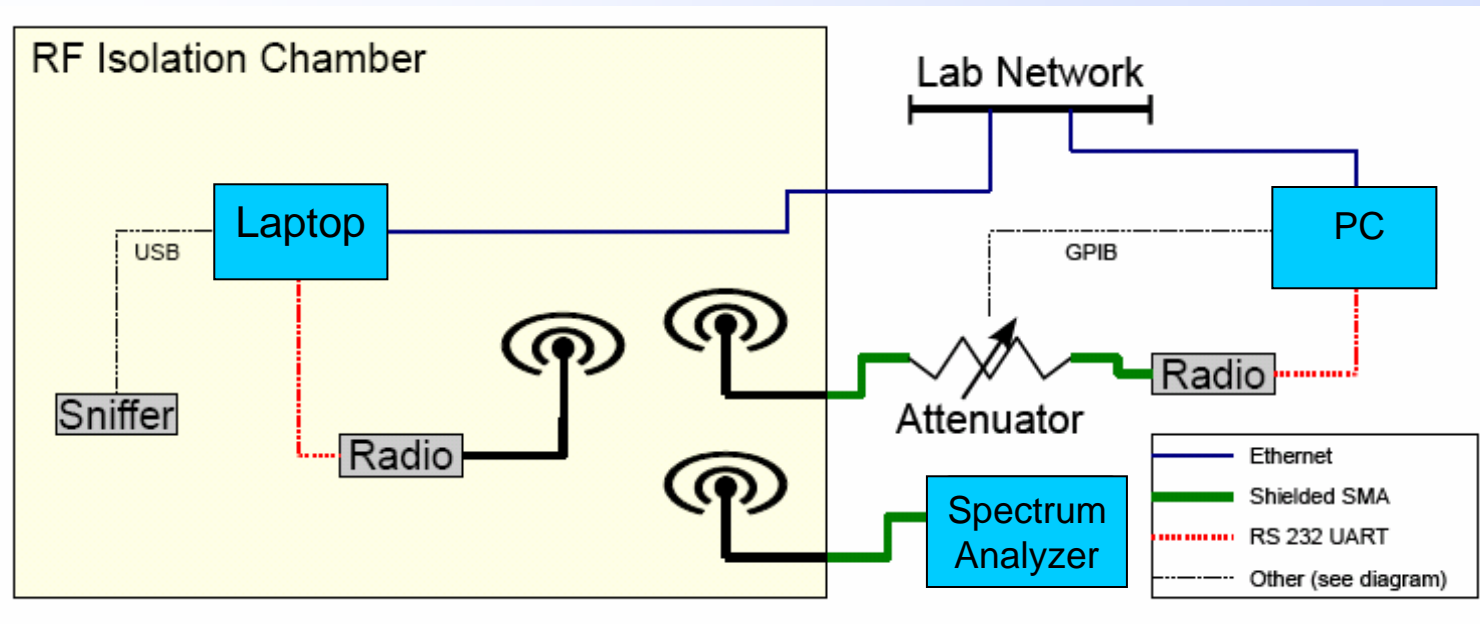
- Determining and documenting causes of wireless link failures/disruptions
- Characterize current link failure detection protocol techniques
- Analyze selected ad-hoc network technologies in meeting design metrics.
- Develop software methods to mitigate effects of link failures/disruptions
- Develop techniques/protocols to allow faster network convergence.
- Work within standards bodies to incorporate the new protocols or protocol modifications



# Link Failure Detection Lab Setup

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# Communication Device Development

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- Development of necessary communication transceiver and antenna components, in an integrated package less than 1in<sup>3</sup>, to operate within a constrained environment (ex. airfoil).
  - Must be compatible with sensor elements
  - Must be low-power to accommodate energy harvesting/scavenging methods
  - This work is being coordinated with a High-Temp Communication Device development activity within the IVHM Hazards Element, being conducted by Dr. George Ponchak and Dr. Gary Hunter.



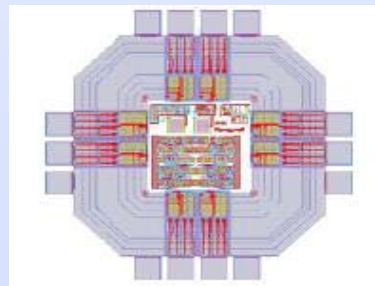
# Offboard Antenna Development

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Develop physics based models for robust multi-beam broadband IVHM data communications, which will enable a conformal design and is able to maintain communications links during failure of 25% of the antenna elements.

This work will build upon research begun under NASA's previous Aviation Safety program, which successfully developed a novel optical interface to reconfigurable antenna elements that improved manufacturability and increased antenna gain.



Robust Reconfigurable Antenna



# Schedule

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FY07

FY08

FY09

FY10

FY11

Requirements

EM Modeling for Constrained Environments

Self-Healing Adaptive Networking Technologies

Wireless Communication Technologies

Robust Multibeam Broadband Communications  
Antenna Models



# Summary

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The NASA Aircraft IVHM Wireless Communication Element will develop communications components and systems necessary to achieve a complete IVHM system, through research and development activities in:

- Sensor System Architecture Requirements
- RF Modeling
- Miniaturized Antenna Development
- Fault-Tolerant Network Protocols
- Communication Device Development
- Robust Off-board Antenna modeling