Exploring Passive RFID System in Metal Rich Environments - Application to Rotorcraft Dynamic Component Tracking

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Outline

- **Rotorcraft Dynamic Component Tracking**
  - Concept of Operations, HeloTrack
  - pRFID Implementation, Key Factors
  - Overall Framework Description
- **Increasing Performance of passive RFID Tags**
  - Beamforming
  - Auxiliary Source
  - Placement Algorithms- Computational Aspects
- **Concluding Remarks**

Rotorcraft Dynamic Component Tracking

- **Tracking dynamic components of rotorcraft is crucial to**
  - Maximize/Optimize part life - Economic use of parts
  - Reduce maintenance and inspection requirements - Total ownership cost reduction
  - Increase safety - Reliable component histories and life assessment
  - Support future acquisition activities - Better designs and serviceability

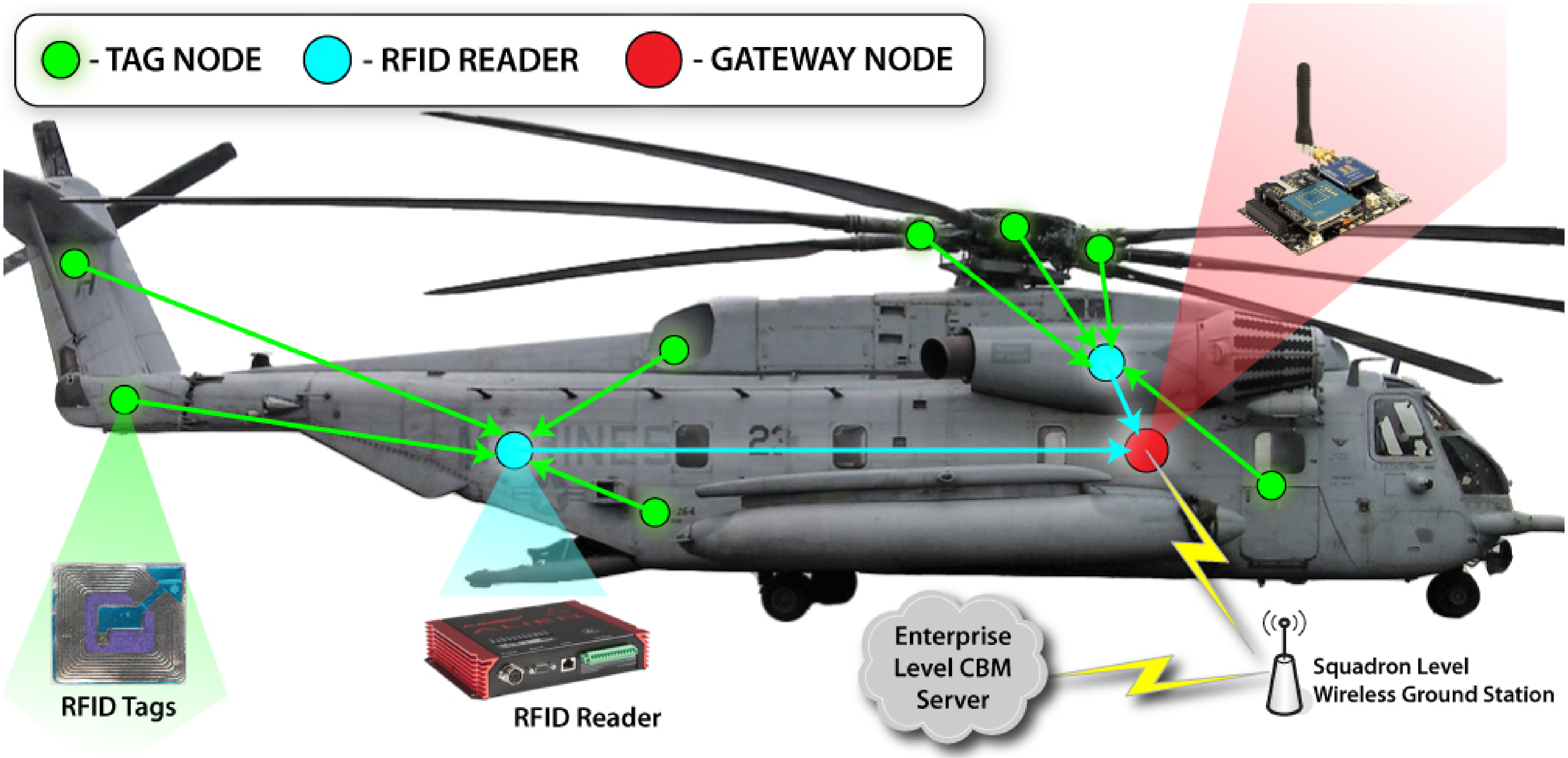
- **The United States Navy (USN) recognizes the importance of enhanced rotorcraft health assessment capability by focusing on**
  - serialization and tracking of fatigue life limited flight critical safety items (CSI)

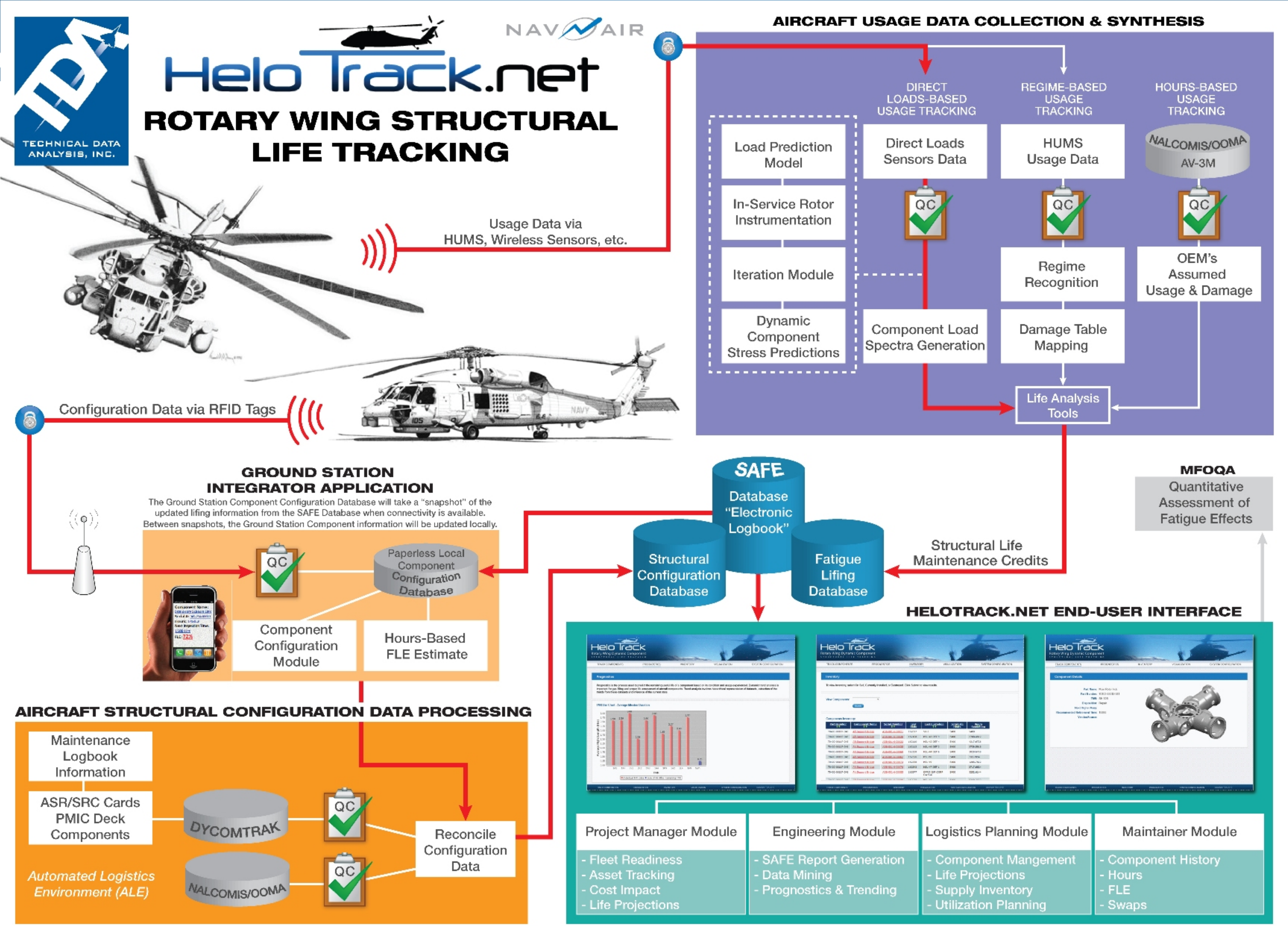
HeloTrack

- **TDA envisioned a framework called HeloTrack in which**
  - component information is collected via a RFID system,
  - rotorcraft usage data (such as HUMS) is processed to make reliable life predictions, and
  - right information is made available to different stake holders to make appropriate decisions for fleet management.
- **Component information as gleaned from the tags will support**
  - rotorcraft configuration management, maintenance, and repair and overhaul shop optimization and life-limited parts monitoring
  - Consequently, the fast maintenance turnaround facilitated by RFID can translate into improved aircraft availability.

- **Objective:**

  "Develop an innovative system for tracking the structural life of rotary wing dynamic components in support of condition based maintenance (CBM) and unique identification (UID) mandates."




TECHNICAL DATA ANALYSIS, INC.
NAVAIR
HeloTrack.net
ROTARY WING STRUCTURAL LIFE TRACKING
AIRCRAFT USAGE DATA COLLECTION & SYNTHESIS
DIRECT LOADS-BASED USAGE TRACKING
REGIME-BASED USAGE TRACKING
HOURS-BASED USAGE TRACKING
Load Prediction Model
In-Service Rotor Instrumentation
Iteration Module
Dynamic Component Stress Predictions
Direct Loads Sensors Data
QC
Component Load Spectra Generation
HUMS Usage Data
Regime Recognition
Damage Table Mapping
NALCOMIS/OOMA
AV-3M
OEM's Assumed Usage & Damage
Life Analysis Tools
Usage Data via HUMS, Wireless Sensors, etc.
Configuration Data via RFID Tags
GROUND STATION INTEGRATOR APPLICATION
The Ground Station Component Configuration Database will take a "snapshot" of the updated lifing information from the SAFE Database when connectivity is available. Between snapshots, the Ground Station Component information will be updated locally.
Paperless Local Component Configuration Database
Component Configuration Module
Hours-Based FLE Estimate
SAFE
Database "Electronic Logbook"
Structural Configuration Database
Fatigue Lifing Database
Structural Life Maintenance Credits
MFOQA
Quantitative Assessment of Fatigue Effects
HELOTRACK.NET END-USER INTERFACE
AIRCRAFT STRUCTURAL CONFIGURATION DATA PROCESSING
Maintenance Logbook Information
ASR/SRC Cards PMIC Deck Components
DYCOMTRAK
NALCOMIS/OOMA
Reconcile Configuration Data
Automated Logistics Environment (ALE)
Project Manager Module
- Fleet Readiness
- Asset Tracking
- Cost Impact
- Life Projections
Engineering Module
- SAFE Report Generation
- Data Mining
- Prognostics & Trending
Logistics Planning Module
- Component Mangement
- Life Projections
- Supply Inventory
- Utilization Planning
Maintainer Module
- Component History
- Hours
- FLE
- Swaps

pRFID Implementation – Key Factors

- **Detection in metal rich environment** - Detection probabilities for solid and non-metallic objects decrease due to radio interference from nearby metals and liquids, Even tags claimed to be specifically for metal components must be tested on a case-by-case basis
- **Effect of object quantity** - Number of objects stacked together affects the average detection probability of an object Objects act as radio signal occluders, Multi-Readers and multi-tagging a component may be a solution
- **Environment** - Ambient radio noise, Environmental conditions such as temperature and humidity, EMI/EMC issues need to be studied very thoroughly
- **Importance of tag orientation** - Ideal orientation may not be achieved with one reader/one tag combination, May need two tags with orthogonal orientation wrt to reader, multiple reader antennas
- **Tag variability** - RFID tags with different chip manufacturers and antenna geometries have different detectability/receptivity properties, No two chips are truly identical due to inherent VLSI manufacturing variations
- **Protocols** –Reliability and Security - Need to use standard protocols, EMI/EMC issues, FIPS 140 - type security
- …

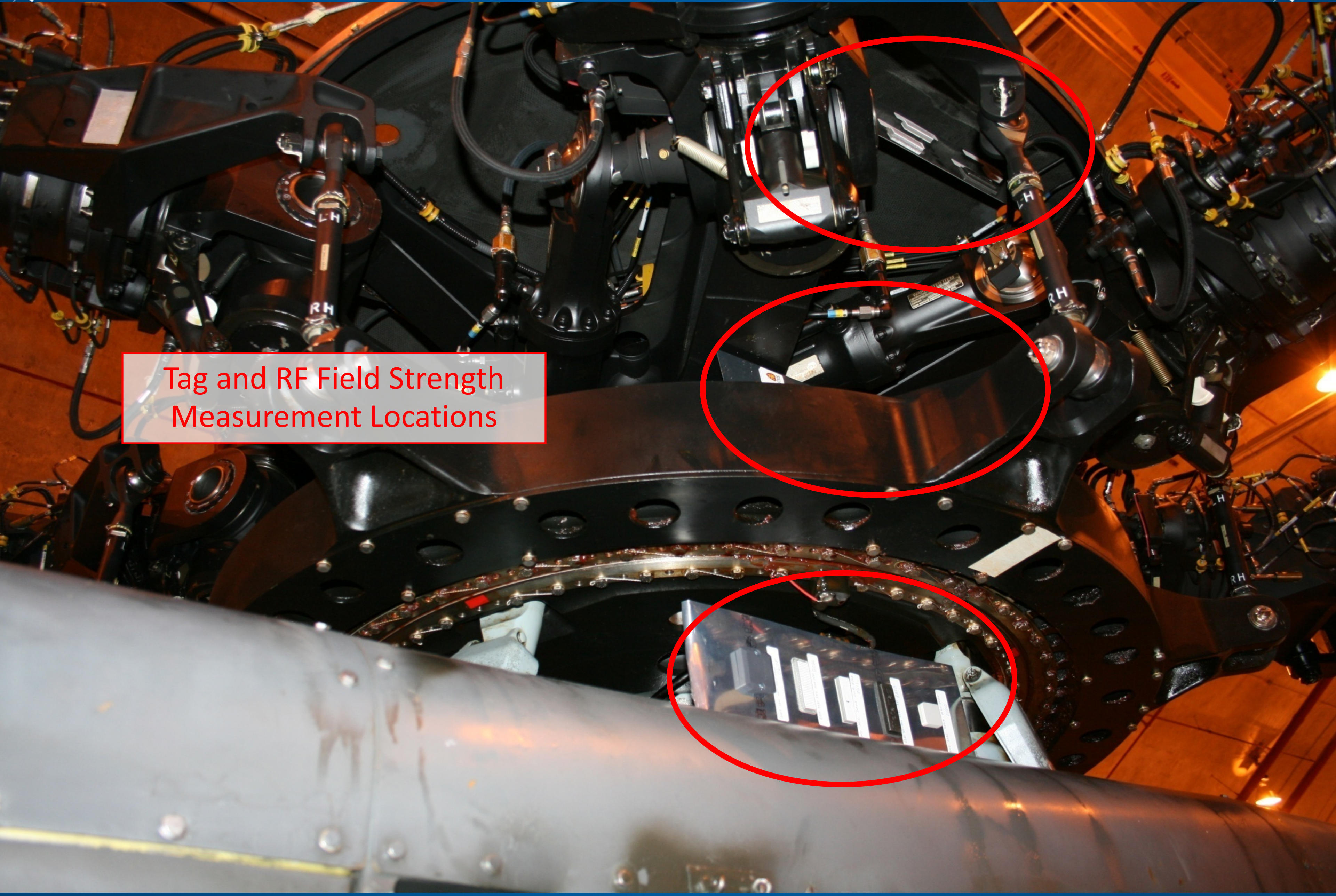
pRFID Implementation – Key Factors

- How to increase the performance of pRFID in rotor head environment –tag readability?
  - How about multiple tags, multiple antenna, and other methods to enhance readability?
  - Where should the reader(s) be placed?
  - Where should the tags be mounted on components for effective readability? Placement algorithm?
- What are the logistics and serviceability concerns?
  - What should be the insulation material, thickness, adhesive etc. for mounting tags?
  - What tests should be done to ensure tag is affixed and will withstand all possible environmental scenarios?
  - What contingency measures need to be taken if the tag is dislodged?

Key Areas of Work

- **Basis RF Measurements for Tag-Reader-Antenna Performance**
  - Controlled Free Space and Constraint Tests
  - On Rotorcraft Tests
- **Work in Progress - Increase pRFID performance in metal rich environment**
    - Beam Forming
    - Auxiliary Source
    - Optimum placement and configuration
    - MIMO/ multiple antenna
  - Lab and Field Tests, System Integration Tests
  - Miniaturization and Efficiency

Rotorcraft Tests



Test Program Conclusions

Key Areas of Work

- Results indicate that tag type/construction is the biggest driver of system performance
- Tag orientation with respect to the antenna seems to be second most important factor
- At close distances, it's possible to read high-quality tags even within a metallic environment
- Due to reflections, it's difficult to predict performance at distances greater than about 16'
- May be possible to mount passive antennas onboard
- Circular antennas are preferred to linear, due to their broader coverage area and equal performance
- Handheld readers are not powerful enough to read tags in the rotor head from the ground

Lessons Learned

- **From TDA's off- and on-aircraft tests:**

  - **Small form factor for both tag and reader-antennas - This is important for application in fleet aircraft. The active tags suffer from the bulkiness because of the batteries. Semi-passive tags that use batteries are also bulky because of the batteries**

  - **Good read range and received signal strength – Important significantly for the metal-mountable passive tags that have no batteries.**

Lessons Learned

- **Performance of pRFID systems can be enhanced** via beamforming, impedance matching, and back scatter boosting techniques, as well as tag placement optimization

- **Implementation of active tag systems is hindered by large tag form factors** as well as undesirable battery maintenance requirements.

Navy Requirements

- **RFID system which combines the size of a Passive RFID and the readability range of an Active RFID - combine the advantages of the passive and active RFID's and eliminate some of their individual disadvantages**
- **RFID tag dimensions and weight should be insignificant and must not interfere with the aircraft functionality - Therefore, tag size optimization is critical to the design and form factor and must be part of the study**
- **RFID tag should be strategically located to remotely access for data communication and power source - placement algorithm**
- **A recharge range of 10 meters is required when using an RF source, preferably a source that complies with FCC Part 15, intentional radiators in license free ISM bands.**
- **RFID tag should be compliant with DoD RFID/UID requirements with a frequency of 433 MHz or 915 MHz and ISO 18000 or ePC, respectively for active and passive RFID tags and**

Our Vision

- **Pursue parallel lines of research in both active and passive technologies**
- **Develop and recommend a complete and optimized system for the unique application of rotorcraft component tracking**

Overall Strategy

Conduct Passive Tag Research

- Boost the back-scatter signal from passive tags through beam forming and impedance matching techniques -
- Boost the back scatter signal from a novel exciter powering method
- Developing a smart placement algorithm involving tag, reader-antenna – computational aspects

All passive RFID tag research will be done using 915MHz tags

Overall Strategy (cont'd)

Conduct Active Tag Research

- **Design of battery-less active tags**
  - Modify chip design to store received power for tag's trans-receiver functions
  - Research how required power can be supplied by power nodes suitably mounted on/off the aircraft

pRFID Performance Improvement Techniques

- **Investigate beamforming techniques for enhancing the passive tag readability**
  - Investigation of beam forming techniques
  - Develop enhanced techniques for improved readability
- **Investigate smart powering of passive tags through auxiliary sources/ exciters**
  - Investigate smart powering options for passive tags through exciters, independent of the reader power.
  - Demonstrated the use of exciters in a laboratory environment
- **Investigate optimum placement and configuration of the RFID tag and reader-antenna systems**
  - Explore efficient placement and relative RFID and Antenna configuration

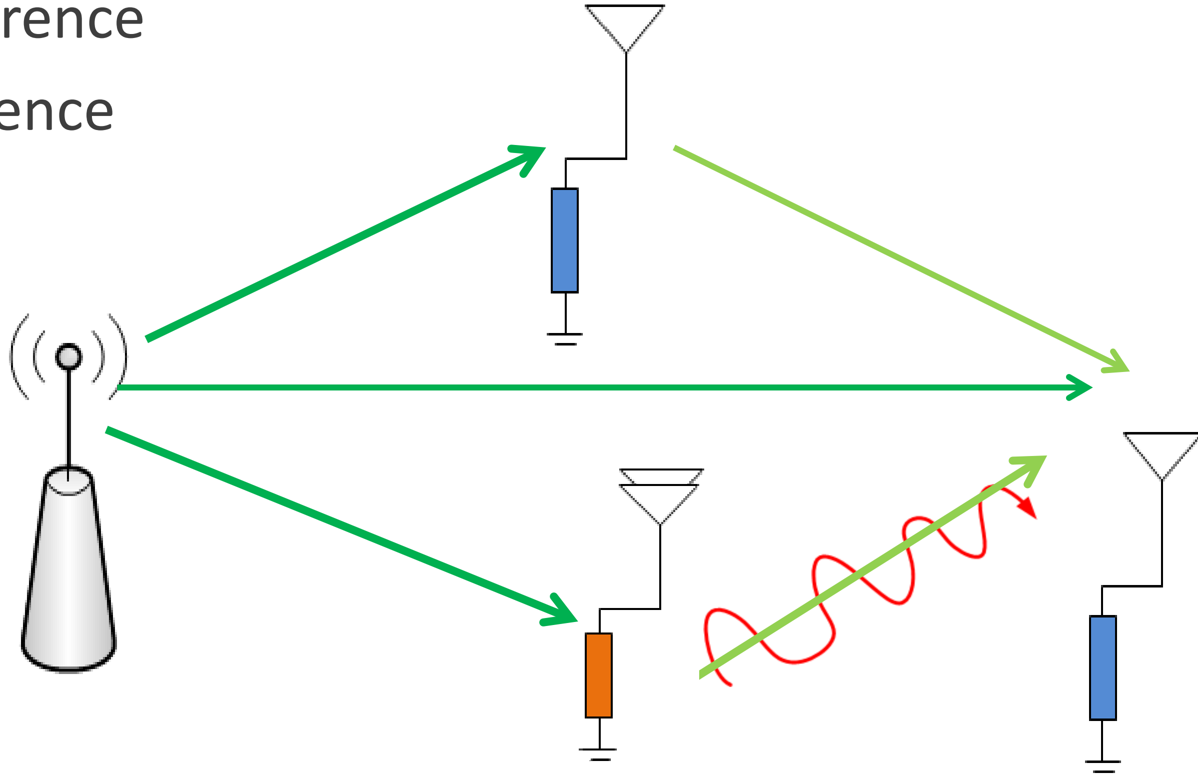
Increasing pRFID performance by Beamforming

pRFID performance degradation

- **Passive RFID tag performance degradation is due to:**
  - Antenna radiation pattern changes – the attached object alters the propagation of the RF signal around the device. The antenna becomes more directional (most signal is radiated perpendicularly to the object’s surface)
  - Impedance between antenna and chip becomes mismatched – due to mutual coupling effect the tag’s impedance changes; this leads to reduced signal strength and quality (i.e. gain is reduced, signal is distorted).

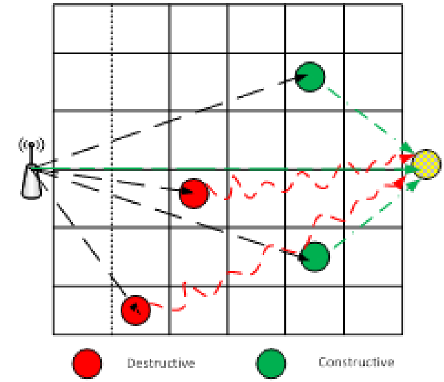
Beamforming Basics

- Direct communication with one tag is affected by the neighbor devices, environment, etc.
- Scattering from intermediate tags – additional modified tags
  - Constructive interference
  - Destructive interference
- What does affect the signal?
  - Positions/geometry
  - Mutual coupling
  - Chip impedance

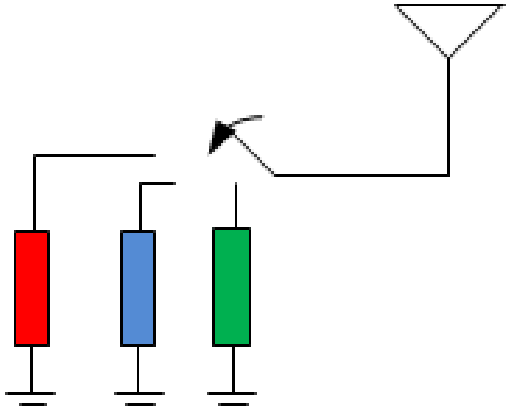


Proposed Approach

- For a dense network one global value of impedance is not suitable
- Our proposed solution
  - Using several impedances in tag's circuitry
    - Matching impedance
    - Inhibition impedance
    - Reflection maximization impedance



- The selected impedance affects the amplitude and phase of the back-scattering signal

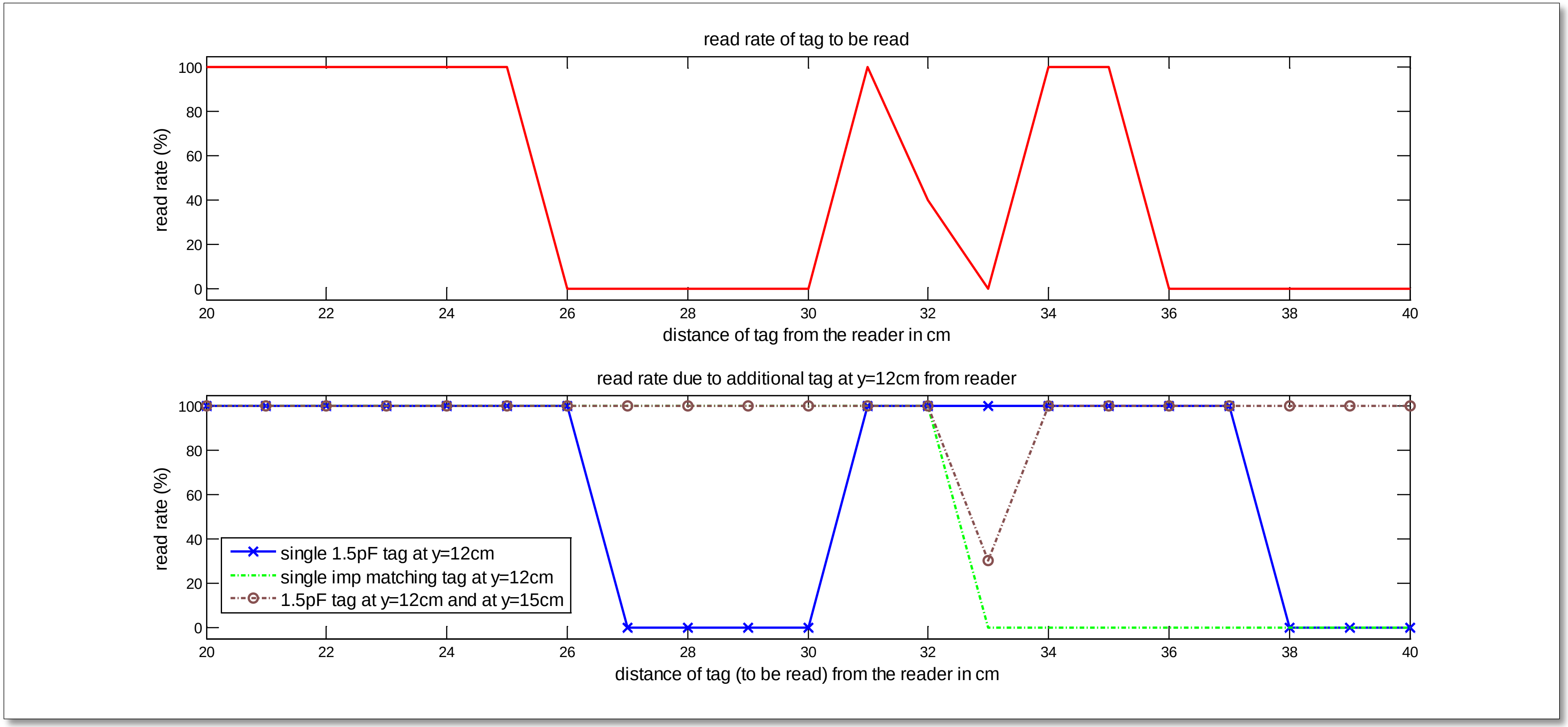


Beamforming - Advantages

- **Directs the RF signal toward the target tag thus increasing the available energy for harvesting**
  - Improves the effective range of the RF-based energy harvesting since it increases power delivered to the passive tags
  - Does not require hardware changes to the tracked tags since only the additional tags have to be modified
  - Additional tags are low-cost since they are slightly modified traditional passive tags
- **Improves the received signal quality by reducing negative interference**
  - The future revisions may include dynamic, adaptive beamforming where the tag design will be changed to enable scattering mode (impedance) switching

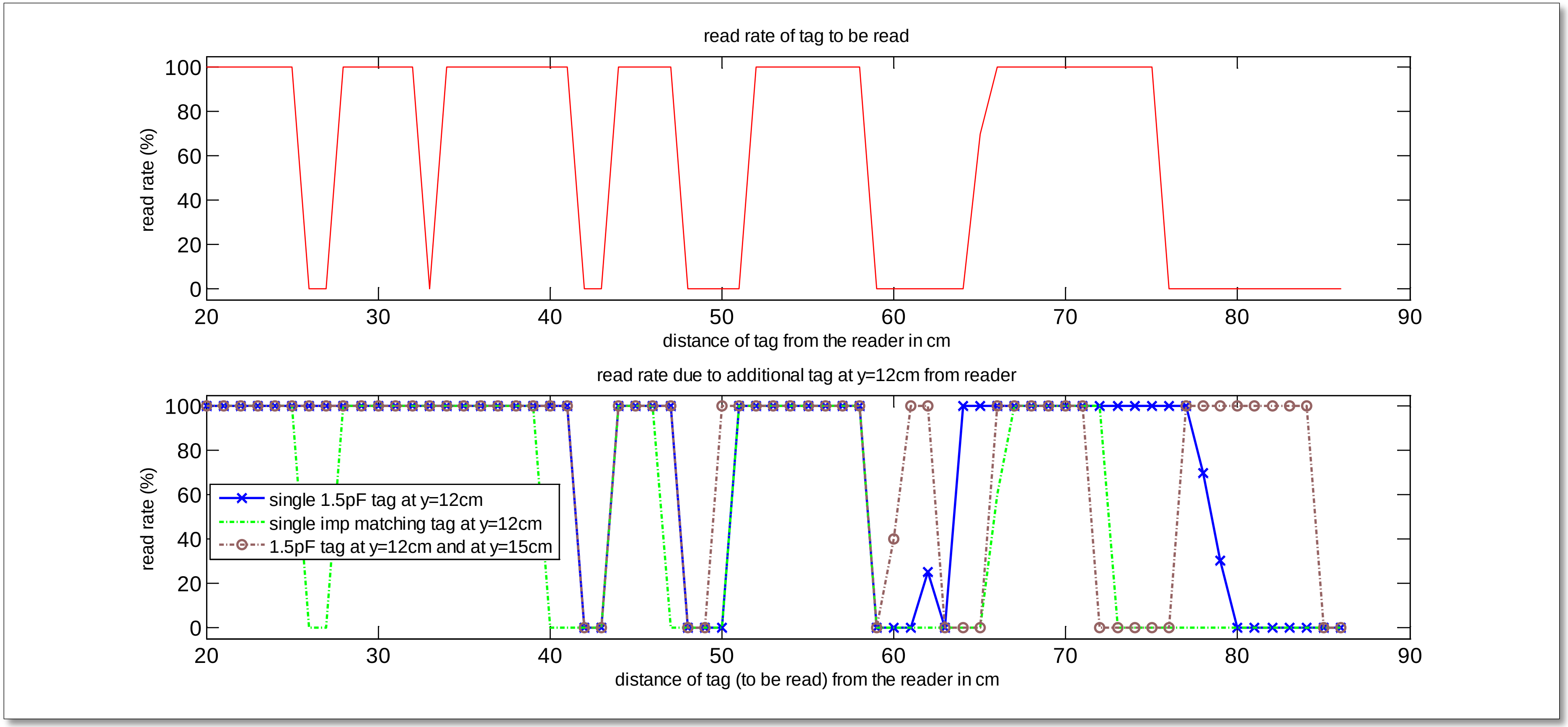
Experimental Results for a Modified Tag (1/2)

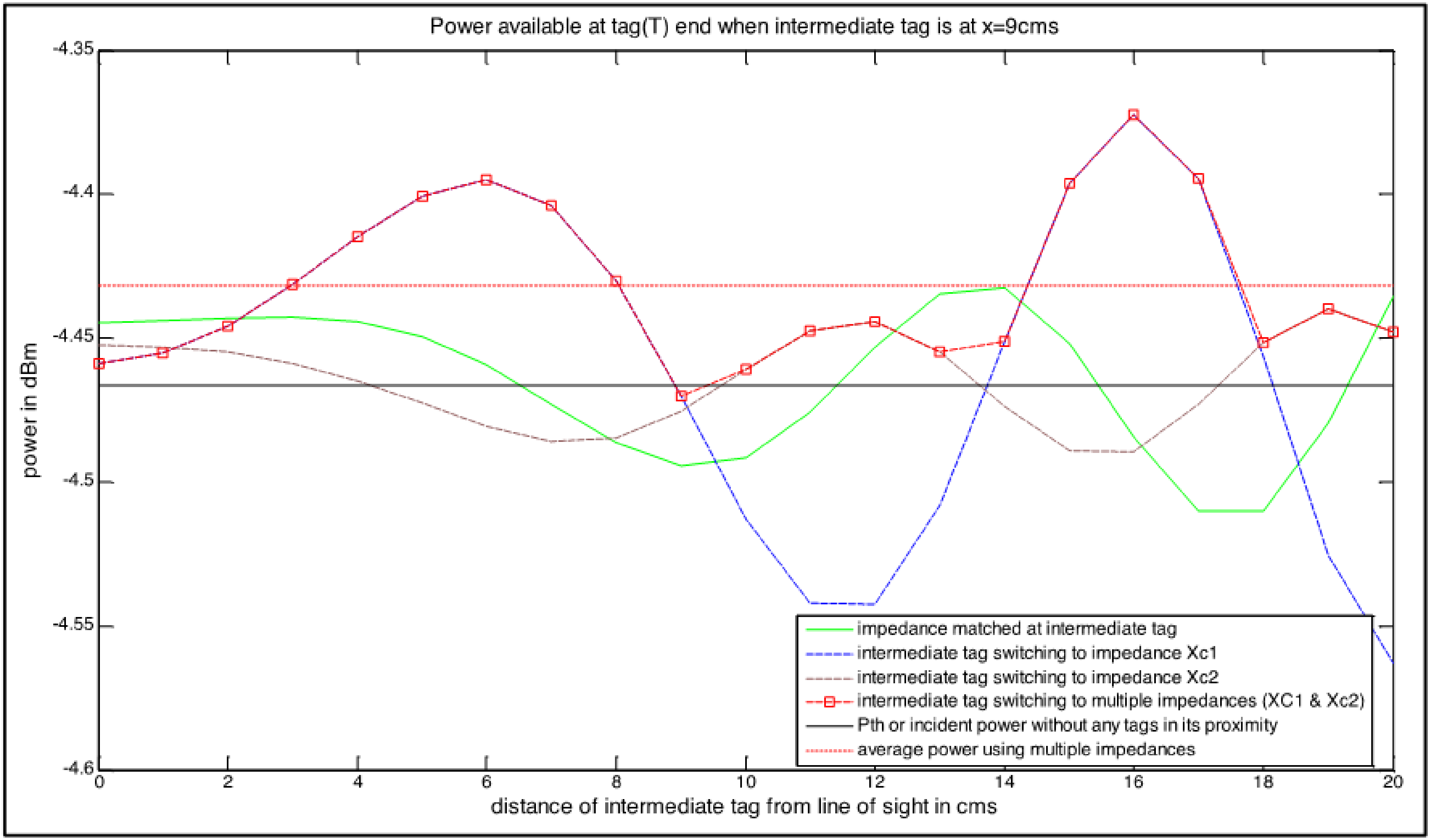
Reader Power 12dBm



Experimental Results for a Modified Tag (2/2)

Reader Power 20dBm




Power available at tag(T) end when intermediate tag is at x=9cms
power in dBm
-4.35
-4.4
-4.45
-4.5
-4.55
-4.6
0
2
4
6
8
10
12
14
16
18
20
distance of intermediate tag from line of sight in cms
impedance matched at intermediate tag
intermediate tag switching to impedance Xc1
intermediate tag switching to impedance Xc2
intermediate tag switching to multiple impedances (XC1 & Xc2)
Pth or incident power without any tags in its proximity
average power using multiple impedances

Increasing Read Range using Auxiliary Source

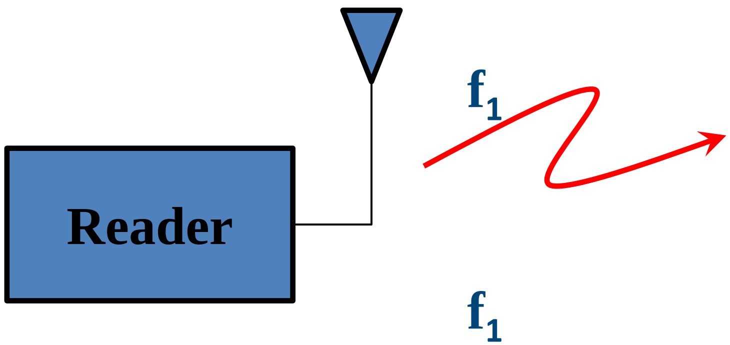
Salient Points

- **Introduce an auxiliary source/external exciter that is independent of the RFID reader module, to power the RFID tag when it is out of range of the RFID reader**

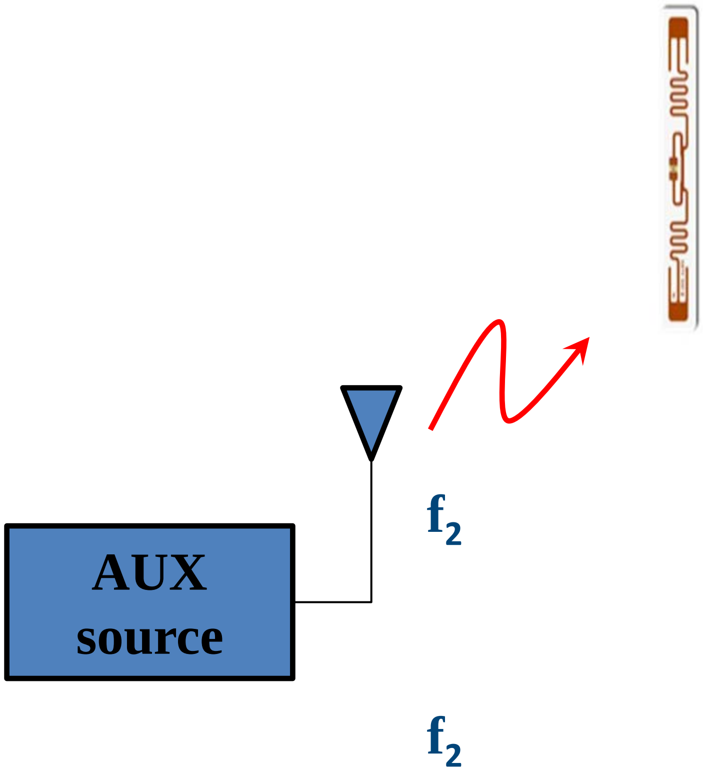
  - The exciter source is only a power amplifier and an antenna and does not require any modulation.
  - In this specific setup, the RFID tag does not depend on the transmitter from the reader for power but rather on the external exciter.

Increasing the range of passive RFID

- The main challenge it to power up the tag.
- Use an auxiliary CW source to power up the tag.



The auxiliary source is an stand alone unit and radiates a CW signal.

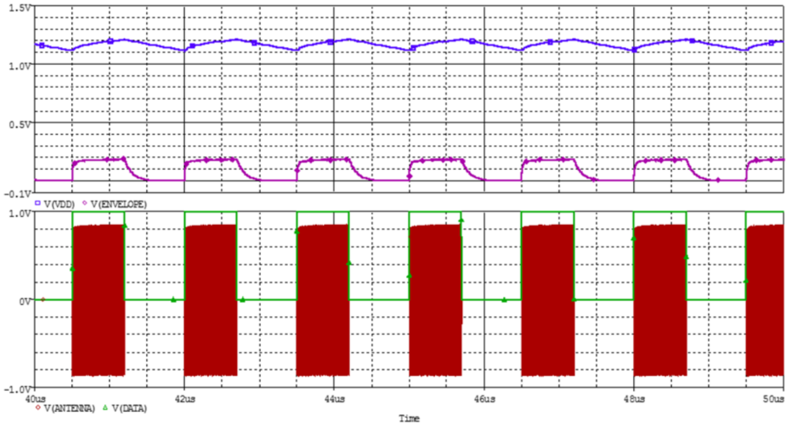


Investigate potential issues with auxiliary source

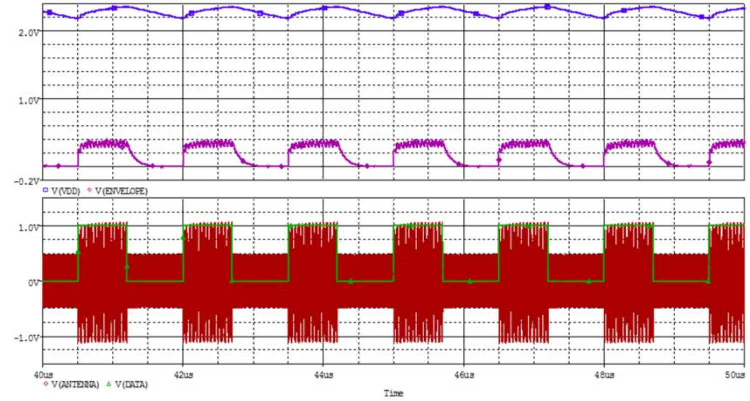
- Effect of the auxiliary signal on the demodulator circuitry
- What is the minimum and maximum required power for the auxiliary source?
- what would be the safe frequency for the auxiliary source?
- Frequency and magnitude of the auxiliary signal should be optimized for the tag to be able to detect the digital data
- Preliminary analysis shows that the proper radiated power at the right frequency range from the auxiliary source will turn on the tag without interfering with the reading process

Auxiliary Source Simulations

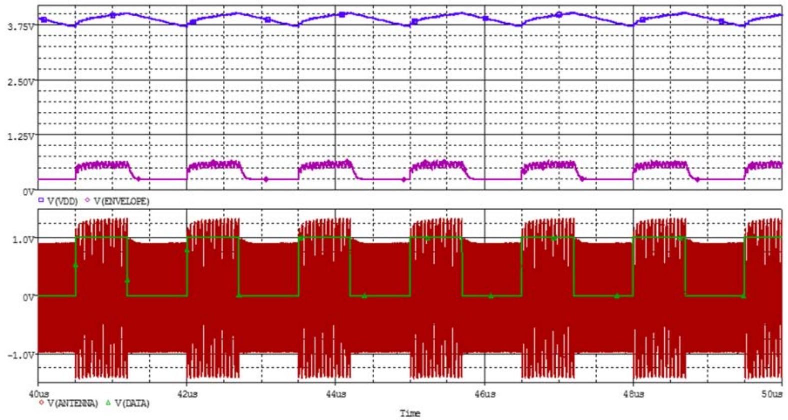
No Auxiliary Source



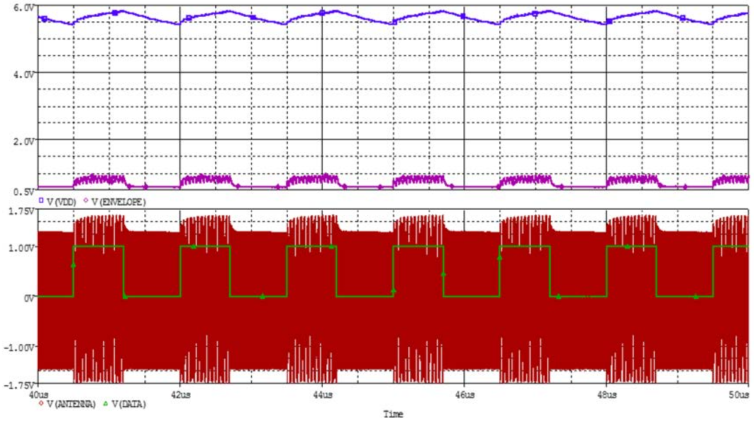
0.5V Auxiliary Source √



1.0 V Auxiliary Source √



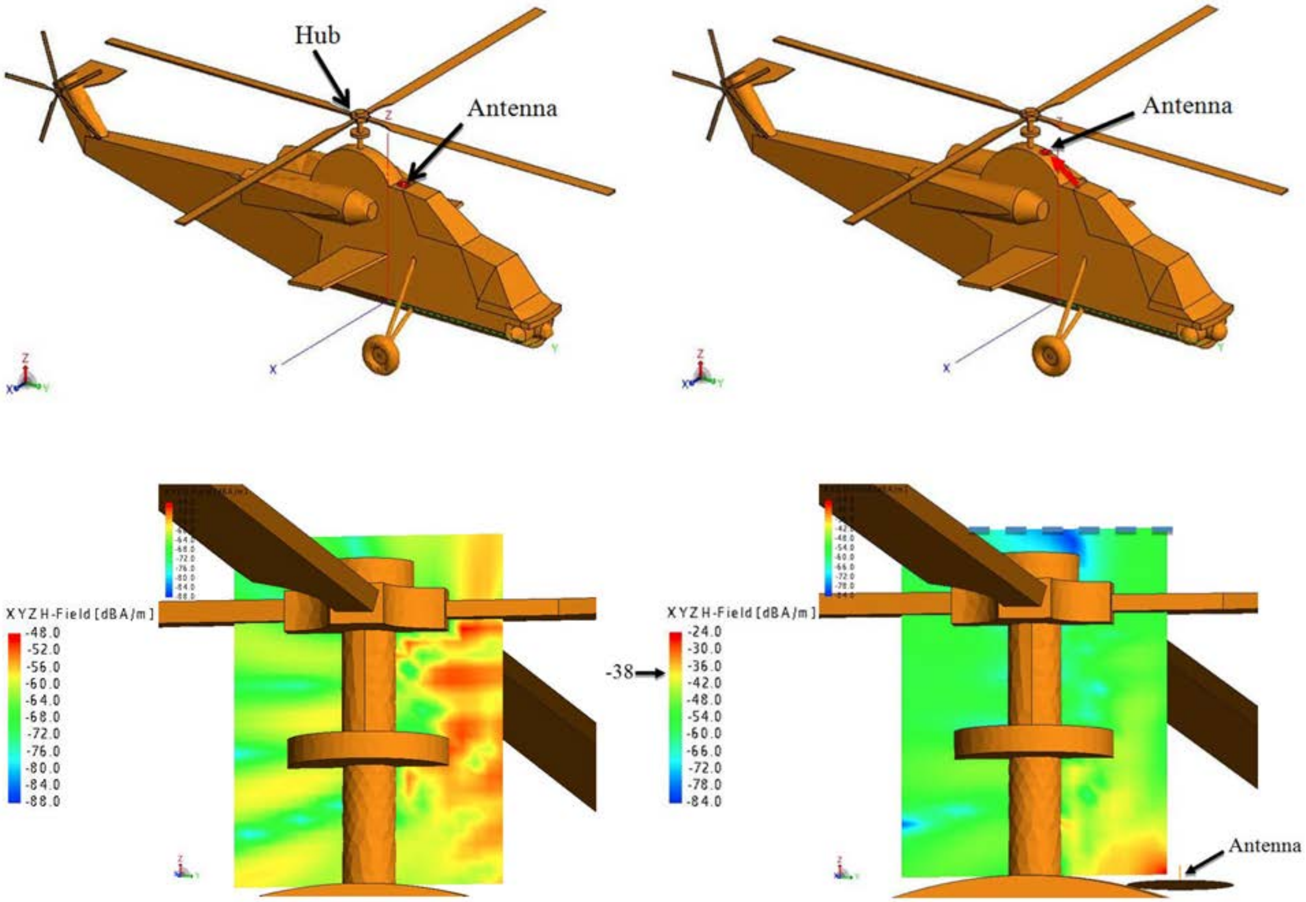
1.5 V Auxiliary Source x



§ **Envelop shows heavy signal quality deterioration with increased level of auxiliary source**

Computational Aspects – Placement Algorithm

Ref: 'Modeling of Passive RFID Systems on Rotorcraft for Tracking Dynamic Components', Applied EM Inc. Report, November 26, 2012, POC: Dr. CJ Reddy



Explore using Both Asymptotic and UTD Techniques

Concluding Remarks

- **Dynamic beam forming and Auxiliary source methods show great promise to increase the pRFID performance when deployed on or near metallic surfaces of the rotorcraft**
  - Based on preliminary lab and on-aircraft tests, we have identified improvements and design changes
  - MIMO/Multiple Antenna technique need to be explored in future
- **Work is progressing in many other areas for optimum placement of RFID system considering EM such that the best communication reliability is achieved**
  - Simulation studies and laboratory-level experimental validation are planned
- **Prototype and demonstrate improved performance for different aircraft configurations**
  - Work towards miniaturization and efficiency

Questions ?