Passive RFID System Enhancements - Applications in Metal Rich Environment

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Nagaraja Iyyer[1], **Prof. Maciej Zawodniok**[2], and **Kishan Goel**[3],

[1]**Technical Data Analysis, Inc.**

[2]**Missouri University of Science & Technology**

[3]**Naval Air Systems Command (NAVAIR) , Structures Division, Patuxent River, MD, USA**

Outline

- Motivation and Background
- Current Effort Details
- On-Going Work
- Envisioned Products & Benefits
- Reference Publications

Passive RFID System Enhancements in Metal Rich Environment

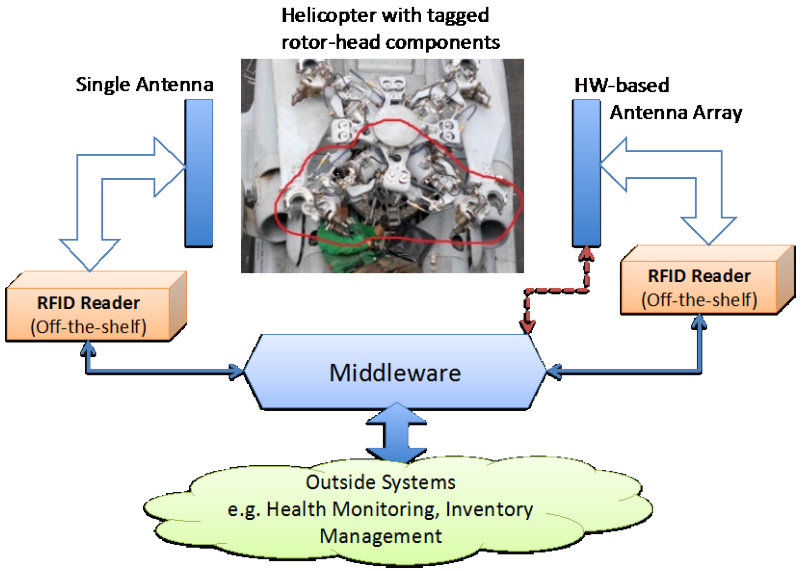
NEED & CUSTOMER REQUIREMENT

Need: To support condition based maintenance (CBM) initiatives and unique identification (UID) mandates the US Navy requires development of an innovative system for tracking the structural life of rotary wing dynamic components.

Value to the Warfighter: An automated system to capture aircraft configuration, what components are equipped

Operational Gap: Eliminates paper records that manually completed and prone to errors.

Customer Specifications: Establishes the current and past history of each critical aircraft component for fatigue life monitoring



TECHNOLOGY DESCRIPTION:

Innovative mount-on-metal passive RFID tags and MIMO reader antenna systems to improve the read range capabilities

KEY INNOVATIONS

- Introduction of dynamic Impedance Switching Network (ISN) within the tag circuitry
- Redesigning of tag antenna and substrate material
- Employing MIMO techniques (multiple reader antennas)

BENEFITS OF THIS TECHNOLOGY

Component Penalization Cost Reduction: Rotorcraft fleet is currently penalized nearly $1.6M per year /platform due to missing/incorrect component tracking history

Efficiency Improvements: The RFID tracking system provides improved quality and access to component data, high reliability, and instant documentation as needed for all stakeholders, while reducing fleet workload and labor hours

Motivation

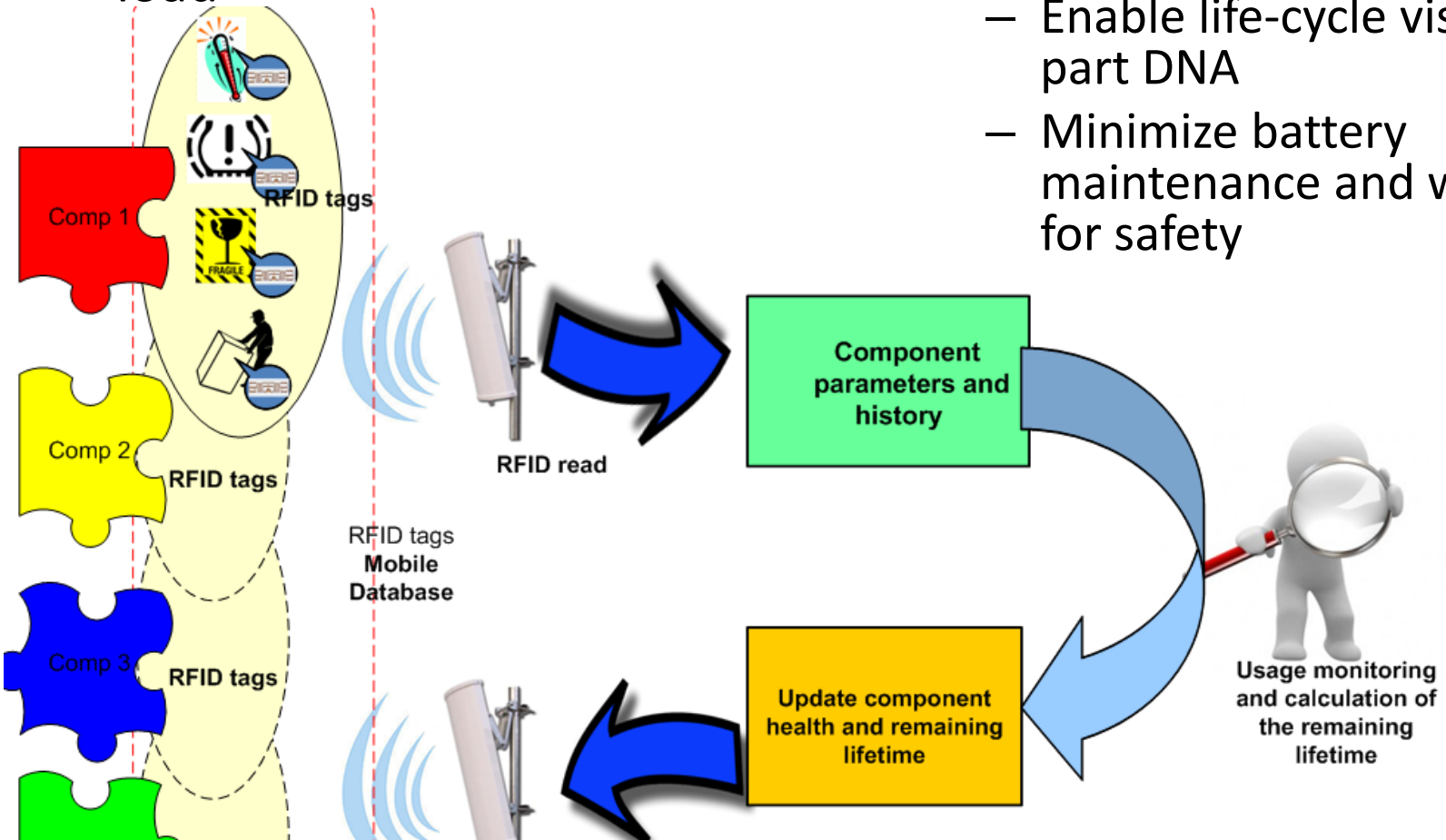
- Besides traditional logistics applications ...
- RFID based IoT enables accurate prediction of remaining life of components
  - Reduce maintenance costs by on-time repair and reuse of components
  - Avoid catastrophic failures
- The proposed ISN-based solution improves reliability of RFID in metal-reach environment,
  - e.g. shipping container, engine compartment, assembly line

http://www.defenseimagery.mil/assetDetails.action?guid=2674ea8e8b029b9e6313baf6795a8d0dcce8735e

Part DNA with RFID Tags

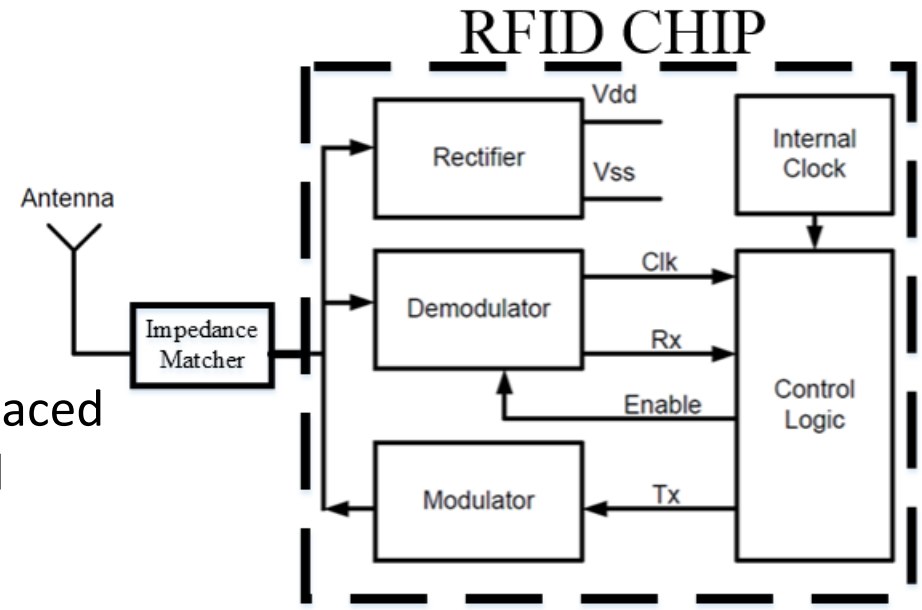
- Cumulative damage of a part throughout its life cycle can be assessed by monitoring the fatigue under a cyclic load

- Wireless, battery-free sensors are preferred to monitor asset health
  - Tracking and inventory
  - Enable life-cycle visibility = part DNA
  - Minimize battery maintenance and wiring for safety



Background

- The passive RFID tag in the UHF harvests low amount of power (mW)
- Main components on a tag:
  - Rectifier
  - De/Modulator
  - Control/Memory Unit
  - Internal Clock
- An impedance matching network is placed on the antenna to match the chip and antenna
- RFID tags that do include impedance matching networks are designed for specific environments and do not operate outside of their design constraint



Current Effort Summary

- Improved read range of passive RFID tags for rotorcraft dynamic component tracking by
  - Introduction of impedance switching network (ISN) for variable impedance
  - Redesign of tag antenna
  - suitable substrate for tag mounting
  - Multiple reader antenna (MIMO) technique

Approach Taken

- **Design and fabricate ISN and WISP based tags to demonstrate improved read performance**
  - ISN and WISP based tags were designed and fabricated for testing. The experiments demonstrated benefit of impedance switching in presence of metallic objects and improved read ranges. Three versions of ISN board were designed and tested progressively to show the benefits of impedance switching
- **Test and verify which tag antenna design is most suitable for rotorcraft applications**
  - Several antenna designs were tested including half-wave dipole, patch atenna, meander antenna, T-matched bowtie antenna and curved bowtie antenna
  - Bowtie antenna provided the best results in terms of read range performance on rotorcraft.
- **Determine which substrate material works best for which material**
  - Studies were undertaken to test different types of substrates (various kinds of plastic , acrylic, ceramic)
  - Acrylic substrate was found to perform better
- **Investigate multiple reader antenna (MIMO) technique**
  - Used software radio (USRP) and blind adaptive beam forming techniques to show how MIMO will enhance read performance
  - Investigated how multiple synchronized antennas in a phase array improves detection range of weak signals
- **Conduct electromagnetic simulations for tag-antenna system in placement algorithm development**
  - Modeled RFID antennas as an integral part of the configuration and computations of the close-in (near fields) surrounding the helicopter
  - Addressed the near-field electromagnetic scattering effects over a wide frequency band

Dynamic Impedance Switching Network (ISN)

- Dynamic ISN's purpose is to change the impedance in the RFID circuitry as suitable to the environment.
- Three revisions of ISN boards were designed and tested and evaluated. Both simulation and experimental results show that ISN improves the read rate by varying the ISN impedance.
- In our experiments, ISN was added to the commercially available RFID Gen 2 tags, to demonstrate the improvement in performance.

ISN with patch antenna (left) and the tag on rotorhub test bed (right)

Redesign of Tag Antenna

- The tag antenna design is a key element
- After several design iterations (half-wave dipole, patch antenna, meander antenna, etc) and testing, we discovered a bow-tie antenna design with increased modulation depth performed better in various scenarios compared to other designs.

Basic T-matched bowtie antenna (left), and experimental test bed on H-60 rotorhub (right)

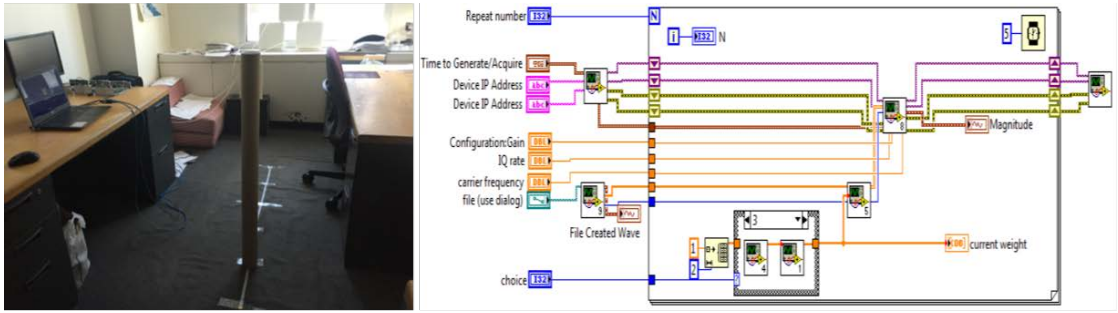
Suitable Substrates

- The substrate material that separates the tag antenna from the base metal was found to be an important parameter
- There is no one common substrate material that works on all metals (steel, aluminum, titanium)
- We found acrylic materials with suitable dielectric constant to be better compared to other plastics used earlier so far

Curved bowtie antenna (left), mounted on rotorhub for testing (right)

Multiple Reader Antennas (MIMO)

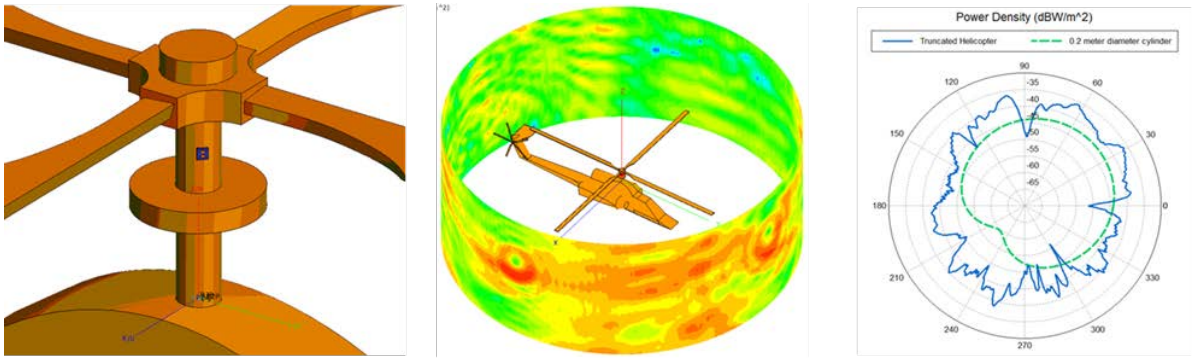
- Employing multiple reader antennas at the same power levels (MIMO) enhances tag read performance.
- We used software radio (UCSP) technique in this effort period as a starter demonstration – software implementation
- Started integrating these techniques into commercially available readers via phased array hardware implementation



Lab checks of MIMO with USRP (left) and block diagram of random beam forming (right)

Tag-reader antenna placement algorithm

- Conducted preliminary work was also carried out on placement algorithm development using electromagnetic simulations to optimize the tag-reader antenna placement for different rotor hub geometries

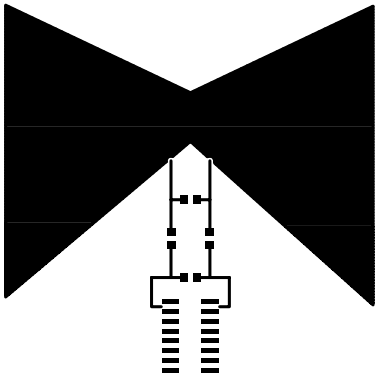


Bowtie antenna on a rotorhub mode (left, and power density distributions about the antenna (900 MHz) (center and left)

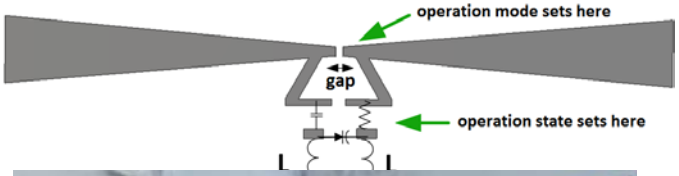
Current On-Going Work

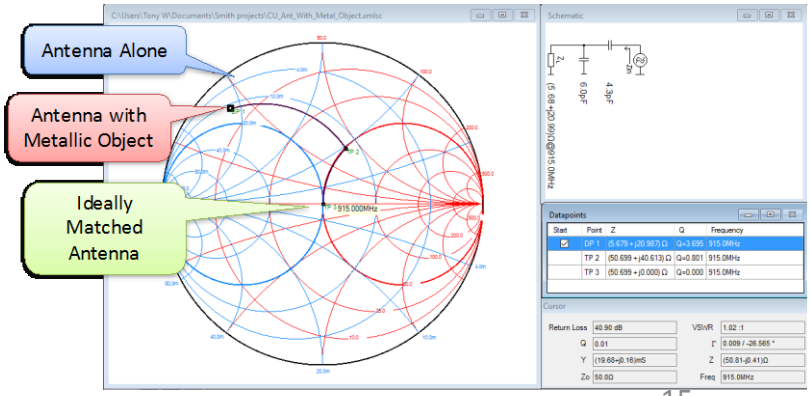
- RFID Tag Antenna Design and Packaging
  - Use the basic design to develop a suite of passive RFID tags for metallic environment considering: packaging (plastic enclosures), antenna redesign with different form factors as needed for different components, integration of ISN with tag antenna, and evaluation other substrate materials, and manufacture of flexible 3D RFID tag antennas of different shapes
- Hardware implementation of antenna array for the RFID reader
  - Software implementation technique using USRP show improved processing gains, however, this does not directly support RFID reader functionality, nor the existing readers are capable of implementing these techniques. Therefore, we are implementing the phased antenna array in hardware that will fully realize the benefits of MIMO
- Middleware and Software Development
  - Coordination and integration of multiple readers will be accomplished by developing a middleware. This will both automatically configure and optimize reader performance and coordinate reading of the tags in the entire system The middleware will also be combined with software with simple user interface on a laptop or mobile device

RFID Tag Design



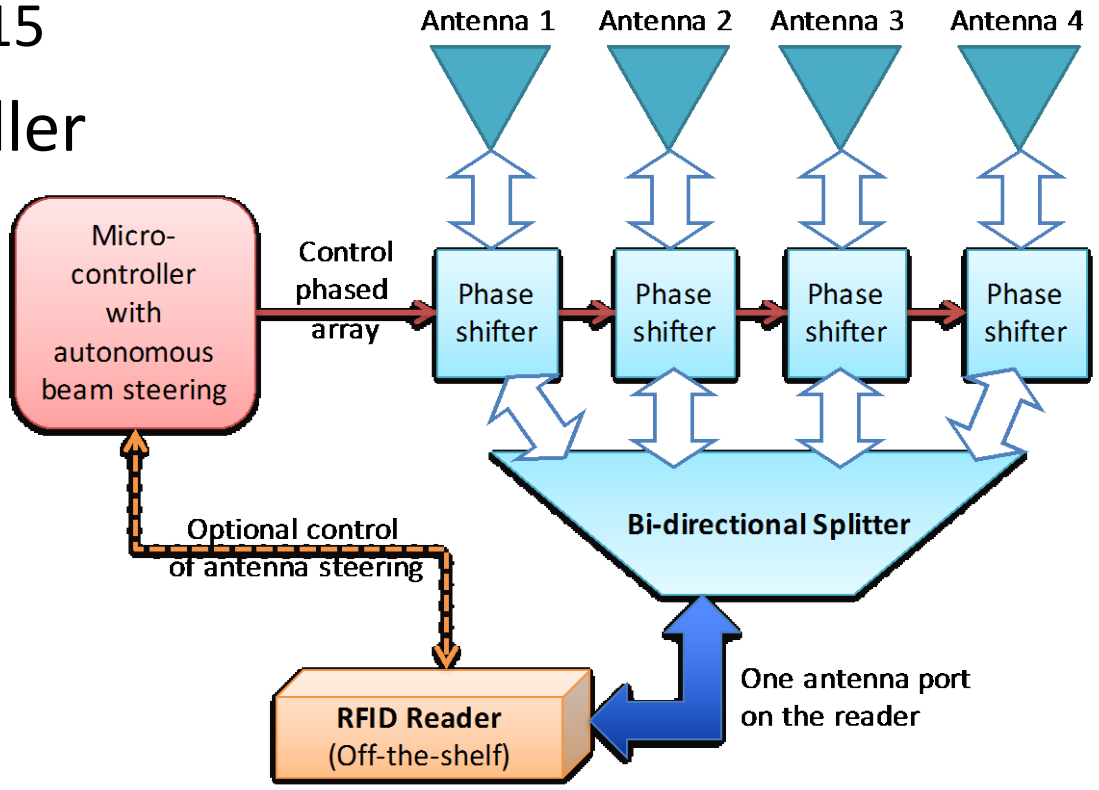
- Design RFID tag for different form factors (elongated, square)
  - Integrate with RFID IC and matching network
- 3D antenna with bendable substrate
- Select substrate to maximize performance
- Package the new tag with suitable substrate





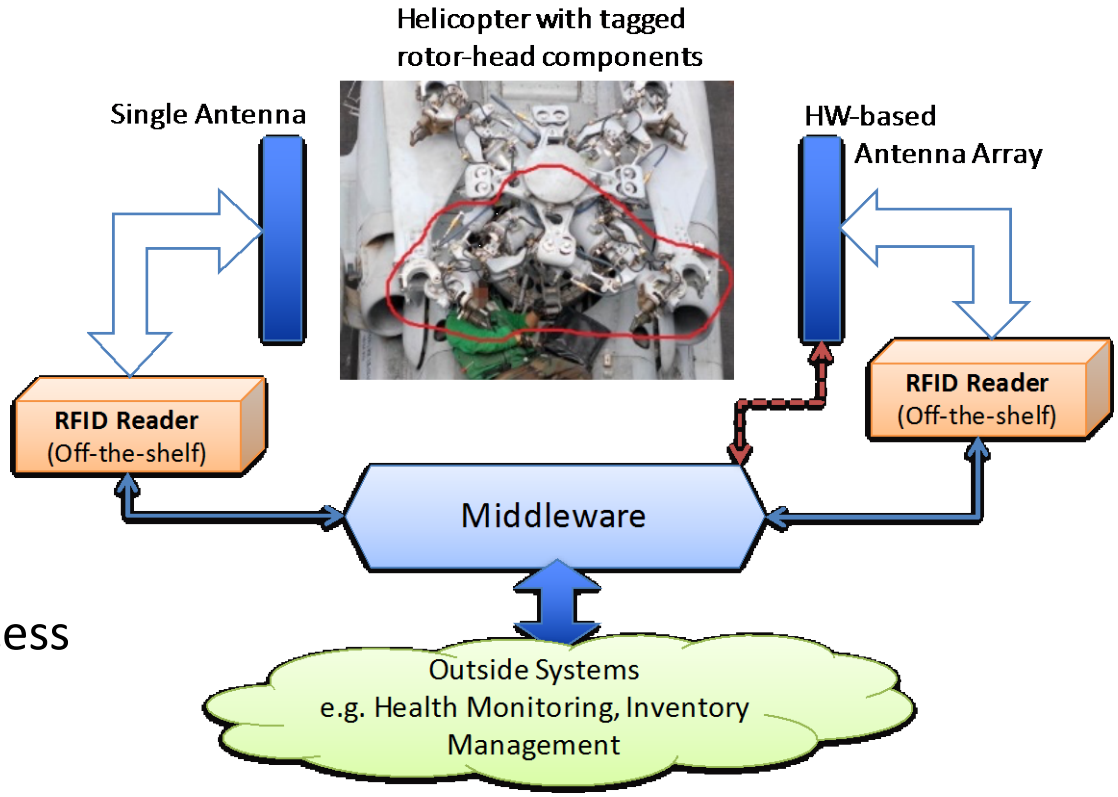
MIMO for RFID Antenna

- Identified component for phase-shifting in 900MHz range with bi-directional operation
  - Skyworks PS088-315
- ARM based controller
  - Beam-forming using phase shifting
- Extended range



Middleware and Firmware Control

- SLLURP library identified as control interface for RFID readers
- Design middleware to support:
  - Multiple RFID readers
  - MIMO embedded controller
- Use SQL database to store RFID reports
  - Used for external access



Envisioned Products

- **Prototype pRFID tags**: Bowtie tag antennas with suitable substrates of different form factors
- **Phased Array Reader System** - Multiple synchronized reader antennas in a Phase Array System implemented in reader hardware
- **On-Aircraft Demonstration** - of pRFID tags and phased array reader system Middleware and software

Benefits

- A system for autonomous tracking of dynamic components on rotorcraft
  - *Passive RFID tag and Phased array antenna system for efficient tracking of dynamic component tracking*
  - *Less downtime and eliminates man-in-the-loop*
- Cost savings by eliminating extensive manual labor for paper recording or web-entries
  - *Enormous benefits by getting aircraft configuration autonomously and updated instantly across all database*

Reference Publications

- S. Ebrahimi Asl, M.T. Ghasr, and M. Zawodniok, “Application of Low Scattering Antennas to RFID Networks” accepted to IEEE RFID 2016 conference (May 3-5, 2016).
- S. Ebrahimi Asl, M. Behgam, M. Zawodniok, and M.T. Ghasr, “Experimental Validation of Minimum Variance Unbiased Estimator of Structural Scattering Coefficient for an RFID antenna Using Linear Model,” Proc. of IEEE I2MTC 2014, pp. 1-1, May 2014
- Asl, S.E.; Ghasr, M.T.; Zawodniok, M.; Robinson, K.E., "Preliminary study of mutual coupling effect on a passive RFID antenna array," Instrumentation and Measurement Technology Conference (I2MTC), 2013 IEEE International, pp.138,141, 6-9 May 2013
- Maciej Zawodniok, Jagannathan Sarangpani, Nagaraja Iyyer, Douglas Algera, Amit Singh, and Nam Phan, “Improving Passive RFID Tag Performance: Application to Rotorcraft Dynamic Component Tracking,” 15th Australian International Aerospace Congress, 2013.
- S. Ebrahimi Asl, M. Behgam, M. Zawodniok, and M.T. Ghasr, “Controlling Mutual Coupling in Neighboring Passive Antennas with Application to RFID Networks”, submitted to the IEEE Transactions on Antennas and Propagation.
- S. Ebrahimi Asl, M. Behgam, and M. Zawodniok, “Measuring the Structural Scattering Coefficient of a Linear RFID Antenna Using Minimum Variance Unbiased Estimator”, under revision for the IEEE Transactions on Instrumentation.