

Miniature UAV Radar System



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Background

- **UAV/UAS demand is accelerating**
 - **Shift from military to civilian applications**
 - **Decreasing acquisition costs**
 - **Increased public awareness**
- **A 2kg UAV hitting a business jet at cruising speed transfers 57kJ while a 20mm anti-aircraft cannon shell delivers 54kJ**
- **Most jet aircraft are only certified for impacts with birds less than 3.6kg. Many UAVs exceed this weight limit.**
- **Sense and avoid systems (e.g. RADAR, cameras, etc...) are necessary for successful integration into the National Airspace System.**

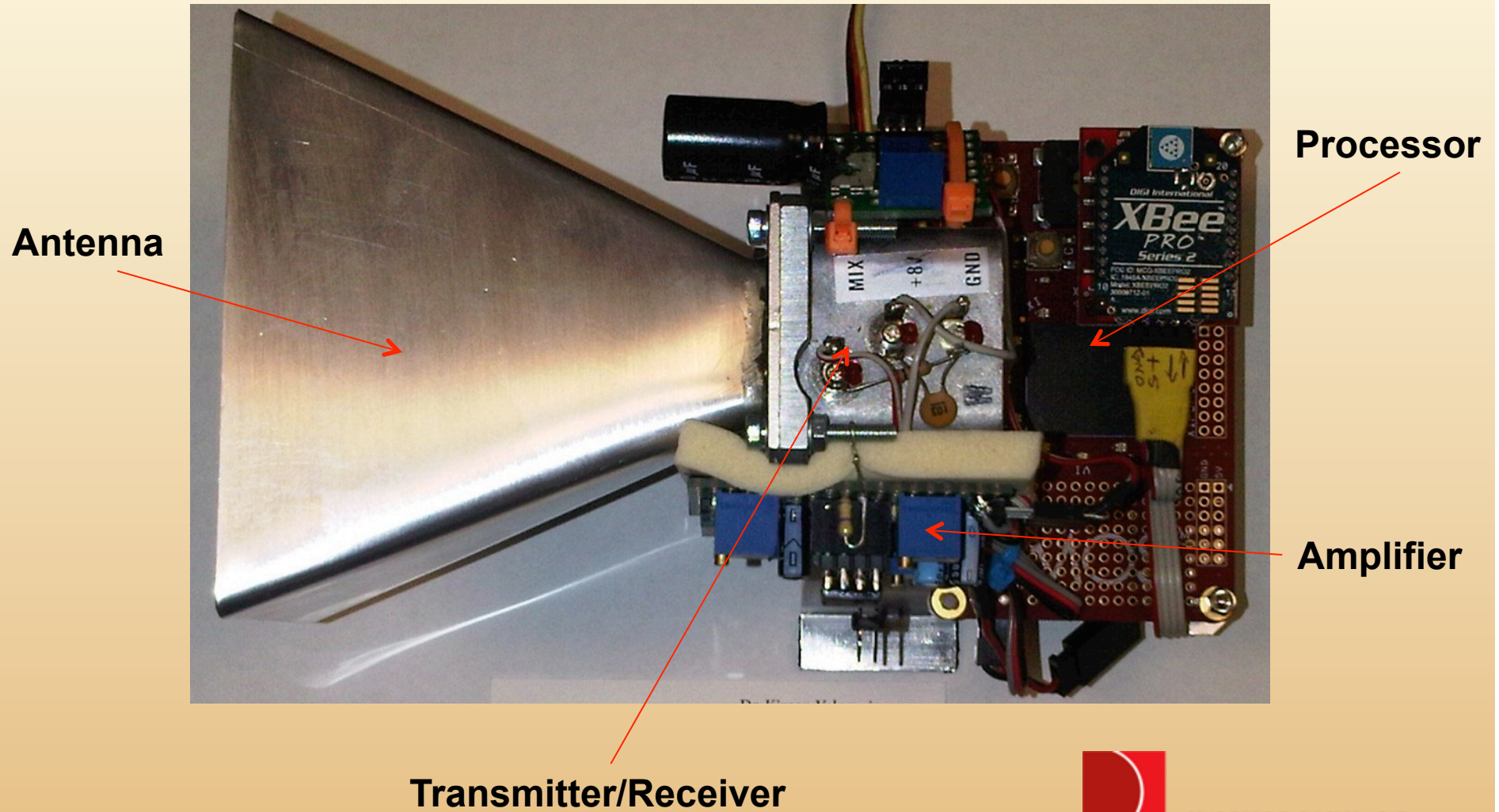


Why Radar?

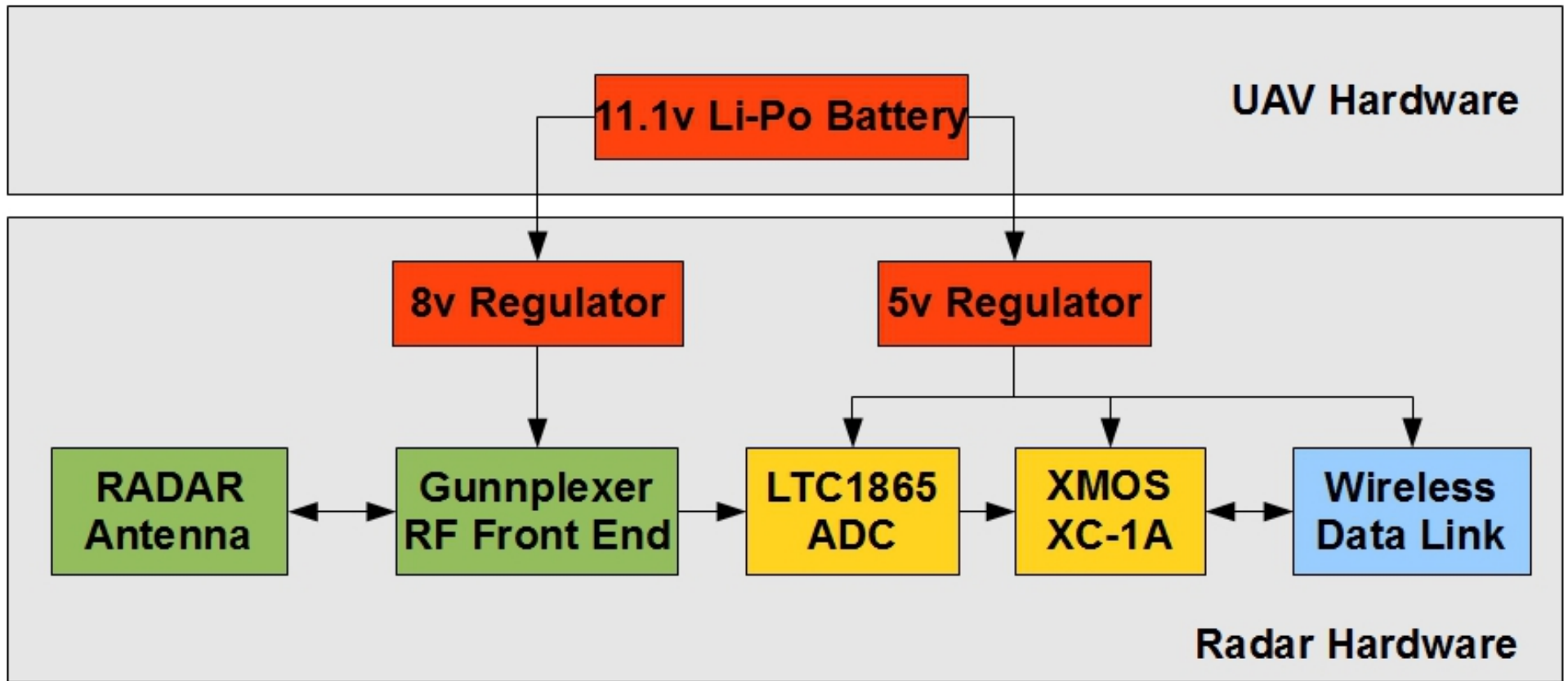
- In addition to optical systems (as required by the FAA) our radar system offers:
 - Lower computational requirements
 - Immunity to sunlight and other light sources
 - Less affected by “optical clutter” (Dust, glass, etc...)
 - Multimode operation:
 - Range detection, Doppler sensing, SAR mapping, etc...
 - Does not require inter-vehicle cooperation as is the case with other systems do (TCAS, PCAS, FLARM)



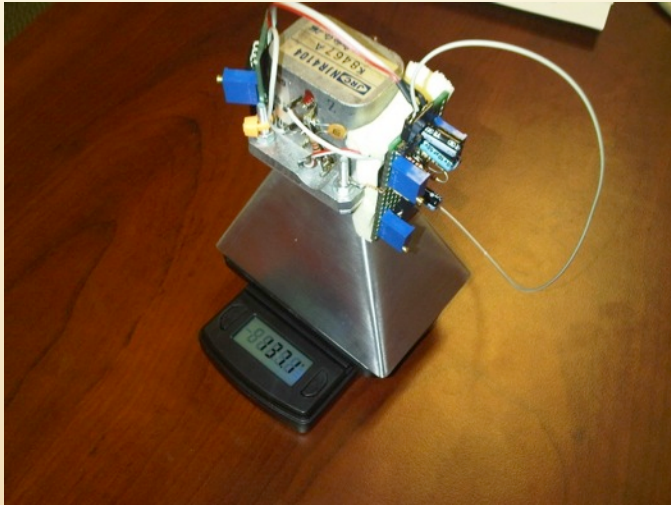
Fully Integrated Working Prototype



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Fully Integrated Working Prototype

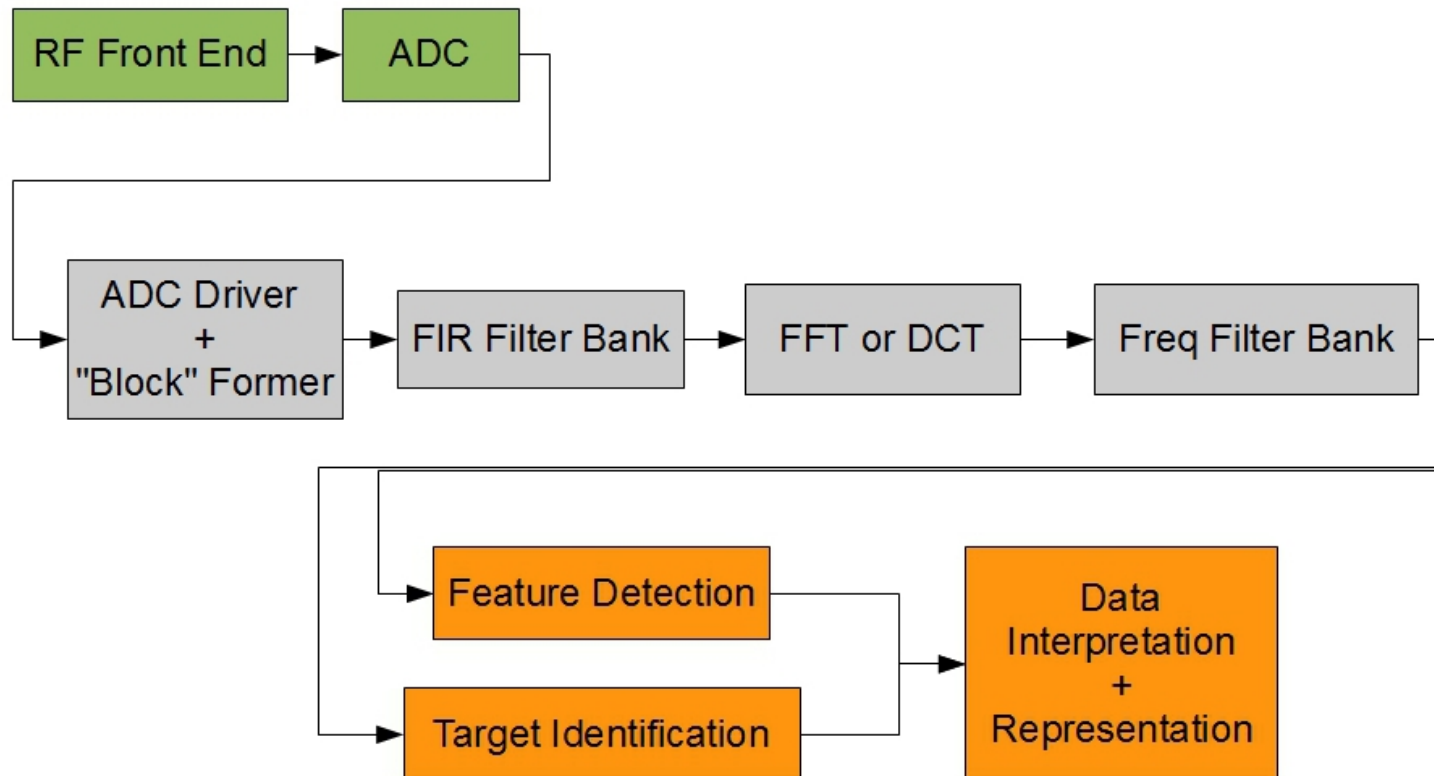


- **Small size: 15.5 x 10 x 9 cm (1395 cc)**
- **Lightweight: 230grams**
- **Power consumption: 4.5W**

- **Fully integrated system capable of independent operation**



Technical Details: Data Flow



Technical Details: Basic Signature Origins

$$\Delta F = F_T \left(\frac{2v}{c - v} \right)$$

C = Speed of light

V = Object velocity

F_T = Transmit frequency (10.5GHz)

ΔF = Frequency shift

$$\Delta F \approx 70.048v$$

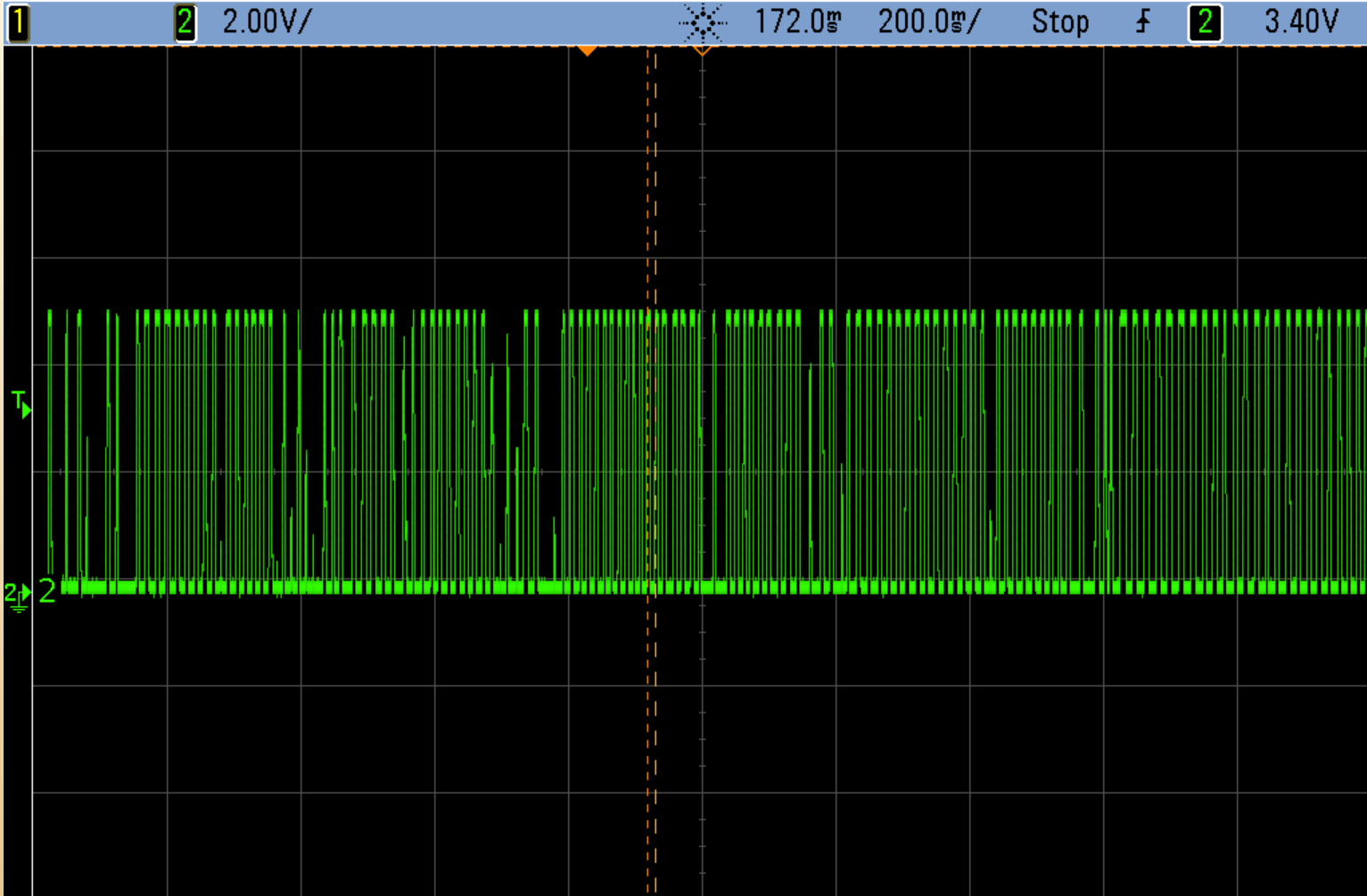


Target Detection (Walking Human)



Agilent Technologies

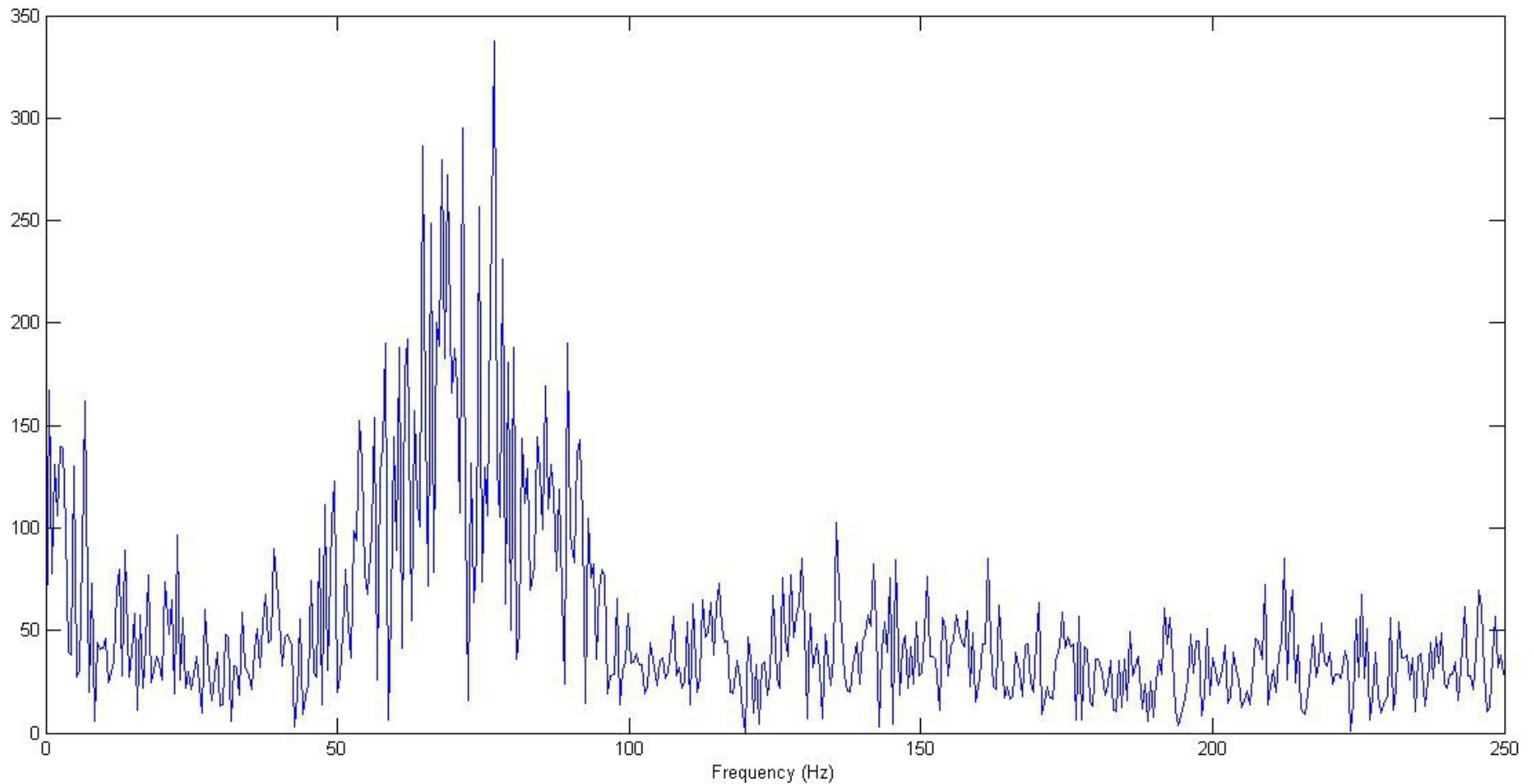
THU SEP 16 02:06:45 2010



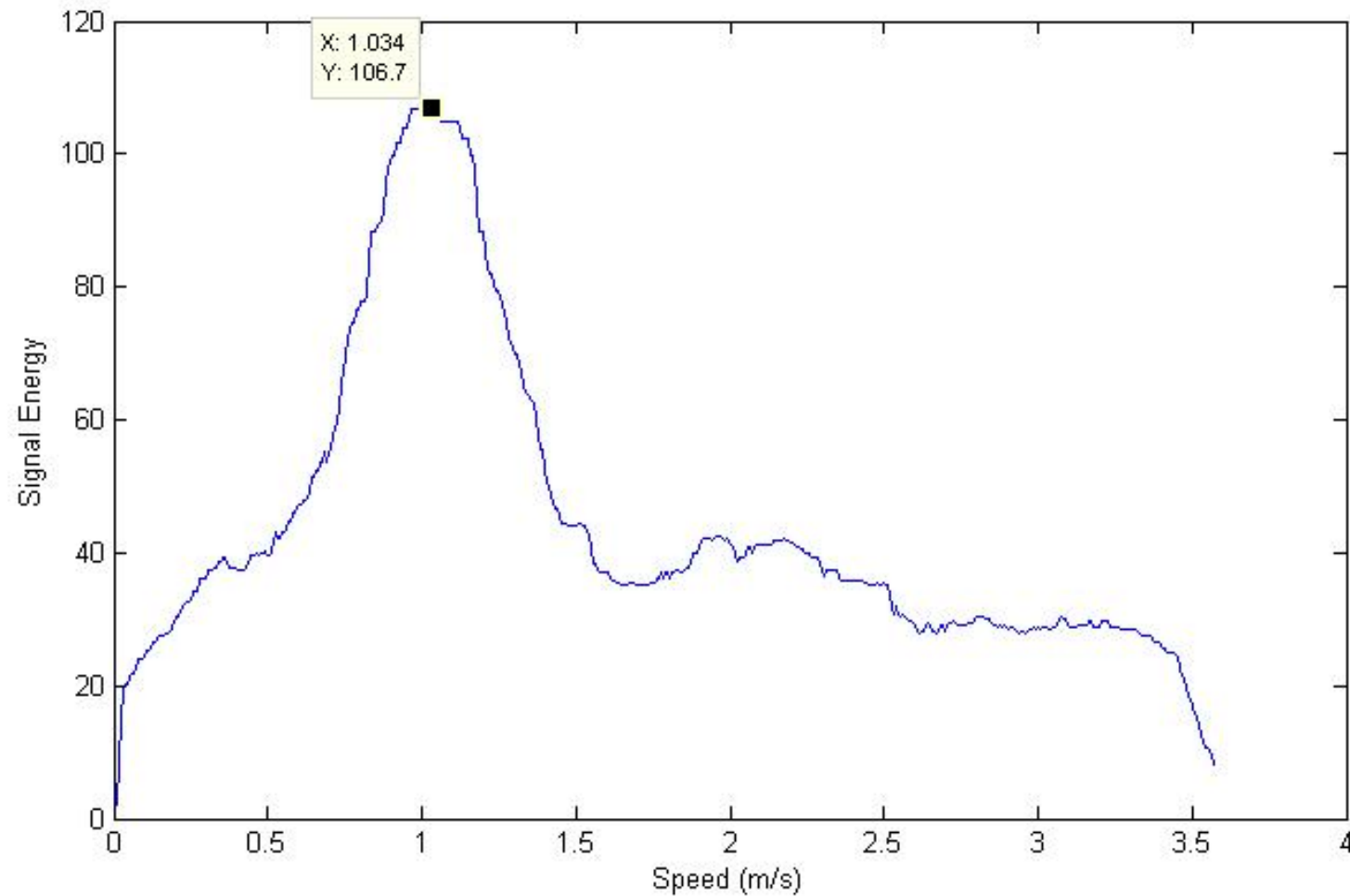
$\Delta X = 12.400000000ms$ $1/\Delta X = 80.645Hz$ $\Delta Y(2) = -16.0000V$

Mode Manual Source 2 X Y X1 90.0000ms X2 102.400ms X1 X2

Target Detection (Walking Human)



Target Detection (Walking Human)



Origin of Complex Signatures: Conventional Helicopter



$$Helicopter_Spectrum(T) = \left(\frac{2F}{c} \right) \left[\frac{\pi d_{mr}}{T} + \frac{\pi d_p}{T} + \frac{\pi d_{tr}}{T/4.24} + Aux(T) \right]$$

d = Component diameter

T = Rotational period of main rotor

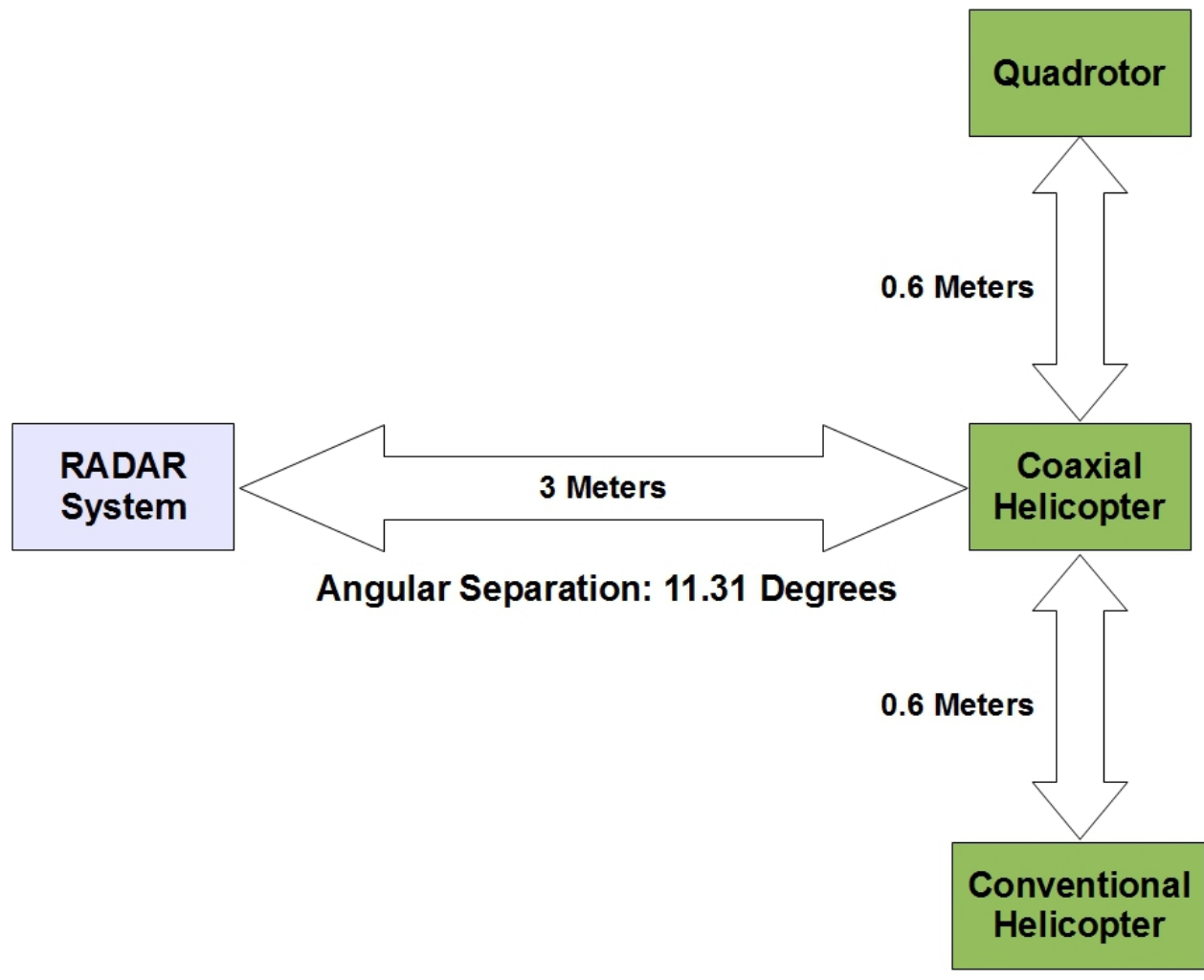
F = RADAR transmit frequency (10.5GHz)

c = Speed of light

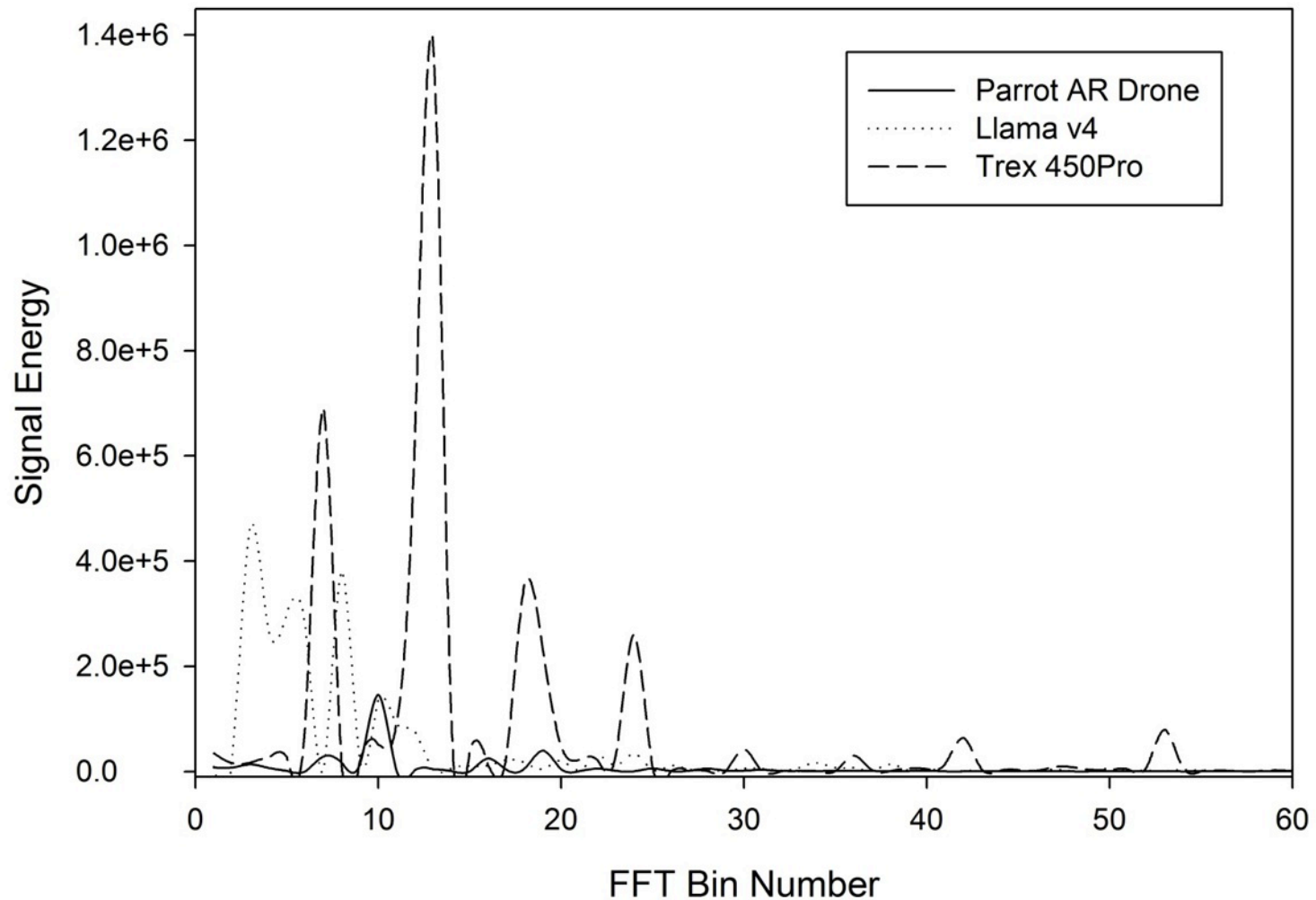


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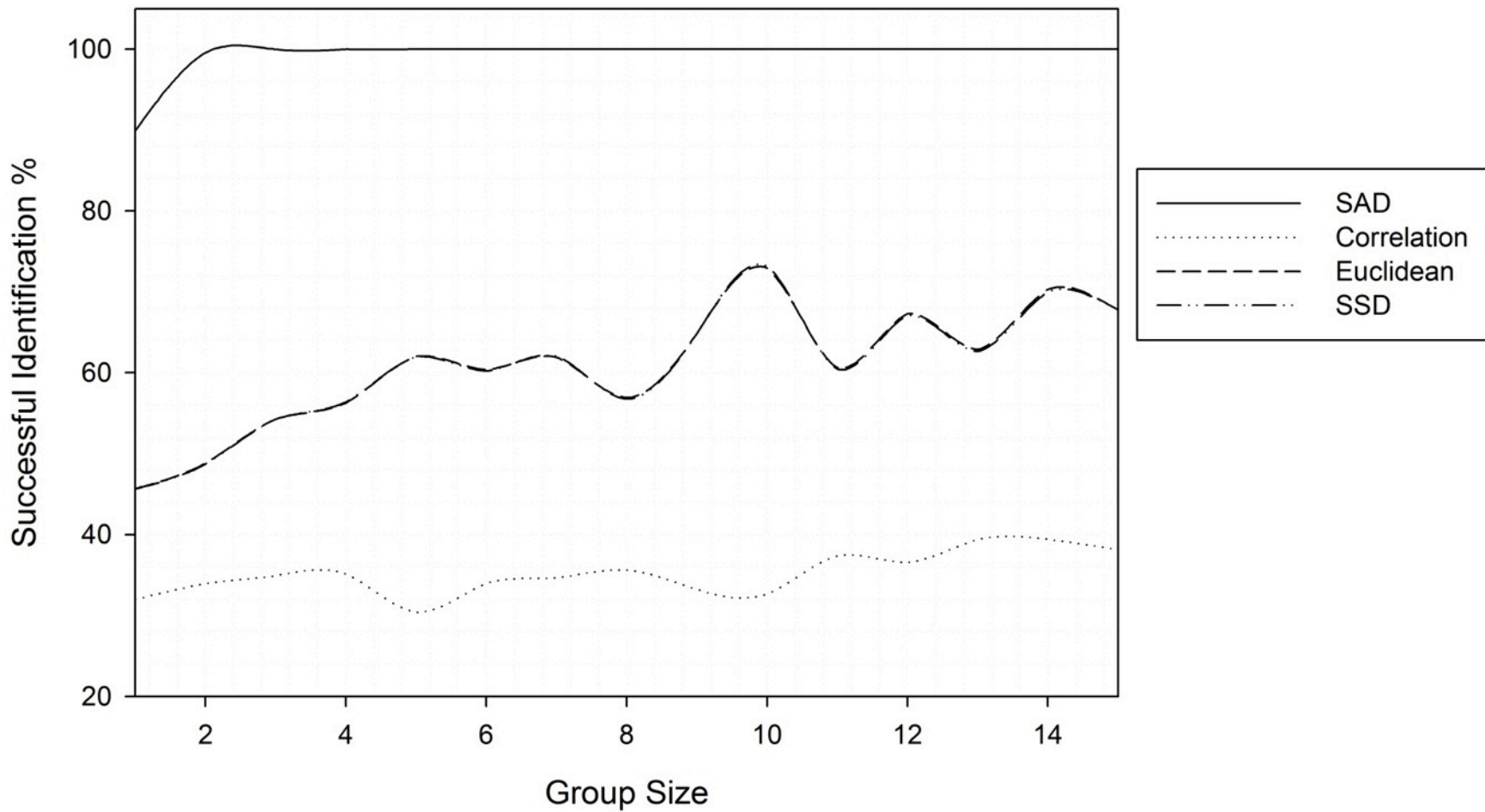
Experimental Setup



Technical Details: Rotorcraft Signatures



Processing Algorithms

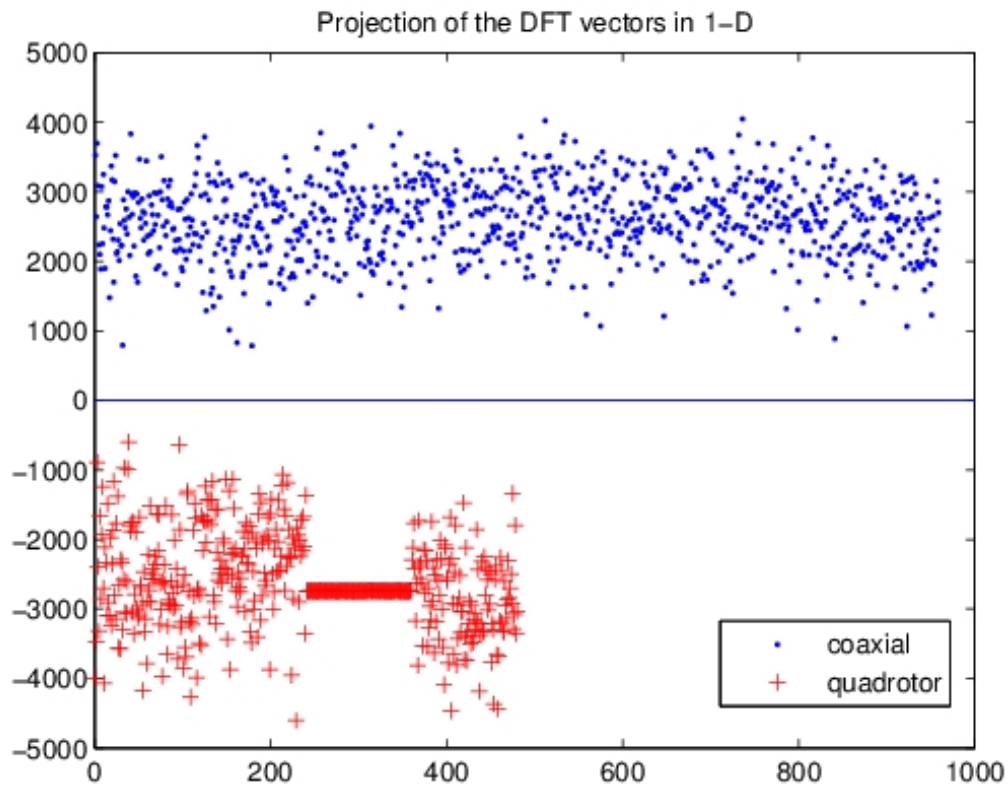


Linear Discriminant Analysis (LDA)

- Collected a dataset of DFT vectors by:
 - Imaging 2 different frames (coaxial, quadrotor)
 - At full and half throttle
 - At a constant distance from the sensor
 - At angles of $0^\circ, 90^\circ, 180^\circ$ and 270° with respect to the sensor
- The result was a dataset with 1439 samples.
- Using LDA we calculated a hyperplane (A) and a threshold (B) such that for any radar sample x :
 - If $Ax + B < 0$ then x is a quadrotor, otherwise it is a coaxial



Linear Discriminant Analysis (LDA)



Samples belonging to the
'coaxial' class

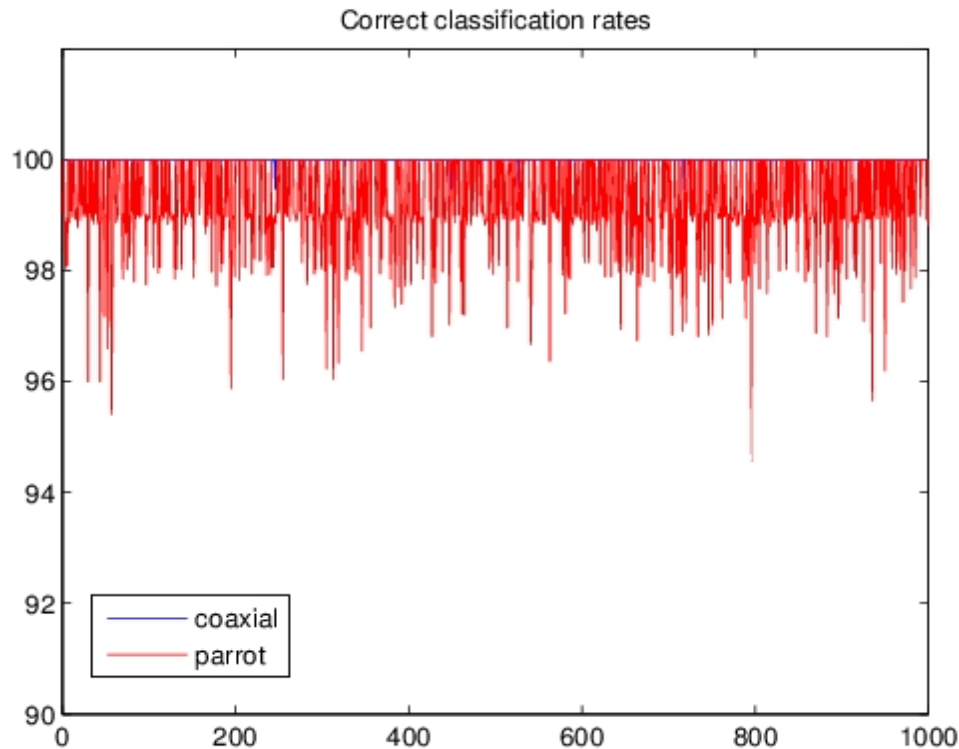
Samples belonging to the
'quadrotor' class



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Linear Discriminant Analysis (Results)

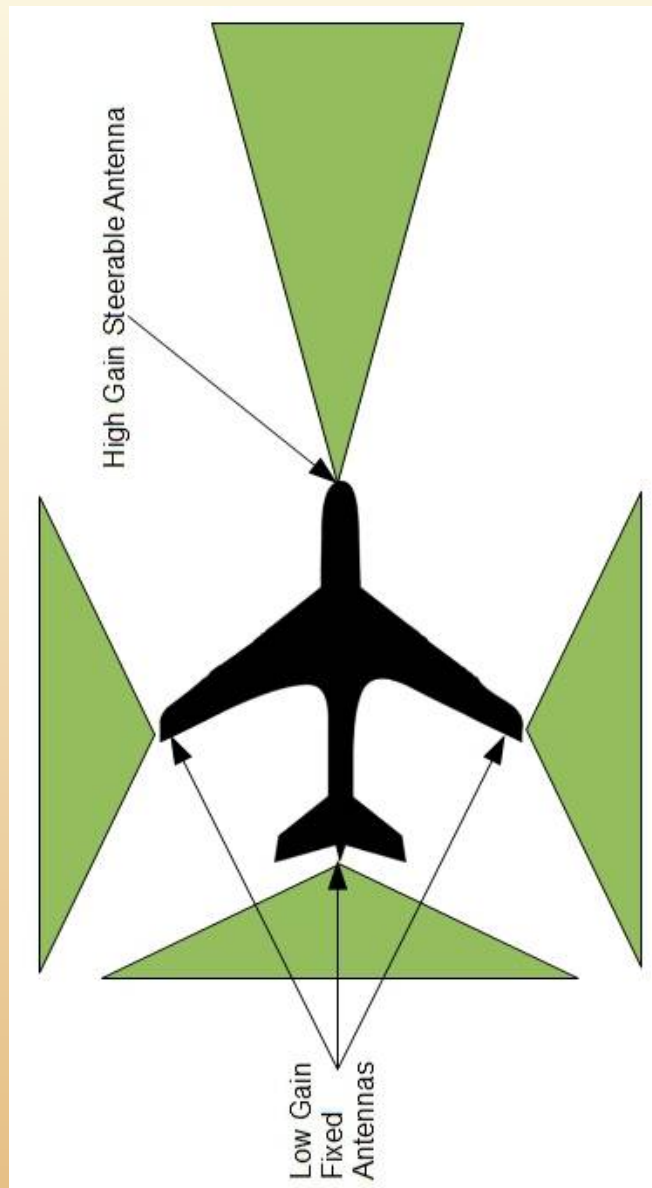
- **Classification rates evaluated by randomly selecting 80% of the dataset as training and the remaining 20% as a testing.**
- **Repeating the process 1000 times yields:**



- **Average correct classification rates**
- **Coaxial → 99.99%**
- **Quadrotor → 99.23%**



Applications: Manned Aircraft Evasion



- **Example UAV RADAR installation:**
 - Single, high power, FMCW equipped, RADAR on forward-mounted Pan/Tilt Module. (Co-located with optical sensors)
 - Multiple, low-cost, conformal Doppler radar modules located around the aircraft detect off-boresight threats
 - Conformal RADAR modules used to “cue” primary sensor suite.



Applications: Manned Aircraft Evasion



- Evasion scenario divided into range “shells”
 - Evasion – Determined by opposing aircraft dimensions and UAV’s acceleration
 - Detection Region – Determined by target RCS
 - Safety region – “N” multiple of the combined Evasion and Detection Regions
- All regions affected by the combined vehicle velocities.



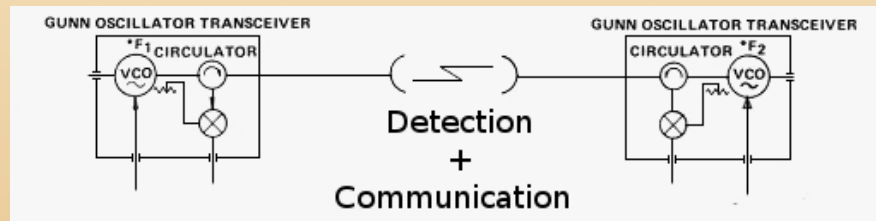
Uniqueness

- **Other devices address larger vehicles, and the associated high acquisition costs hinder widespread implementation**
- **Furthermore, commercially available, miniature airborne radar systems do NOT address the air to air collision scenario. There are, however, systems for the following:**
 - **SAR Mapping**
 - **Radar Altimetry / range finding**
- **Our system is capable of addressing the above scenarios IN ADDITION to air-air collision mitigation**



What can we do with this?

- Detection and identification of air traffic will enable
 - Cooperative UAV behaviors
 - Non-cooperative Air Traffic Collision avoidance
- Additional system benefits (independent of the sense and avoid mission)
 - Faster data communication
 - Signals intelligence:



Future Work

- **Improve antenna design to allow for**
 - **Beam steering**
 - **Target tracking**
 - **Refined target evasion techniques**
- **Outdoor range testing**
 - **Improves power requirement estimates**
- **Development of target library (both manned and unmanned)**



Technical Details: Scattering Regions

