Radar and Wind Farms

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Summary

- Introduction to Radar Basics
- Radar limitations and issues
- Who is objecting to wind farm developments
- Marine radar and wind farm
- Modeling the radar returns from turbines
- Mitigation measures
- Novel materials and lightning protection
- Coming up, in the next training seminar…

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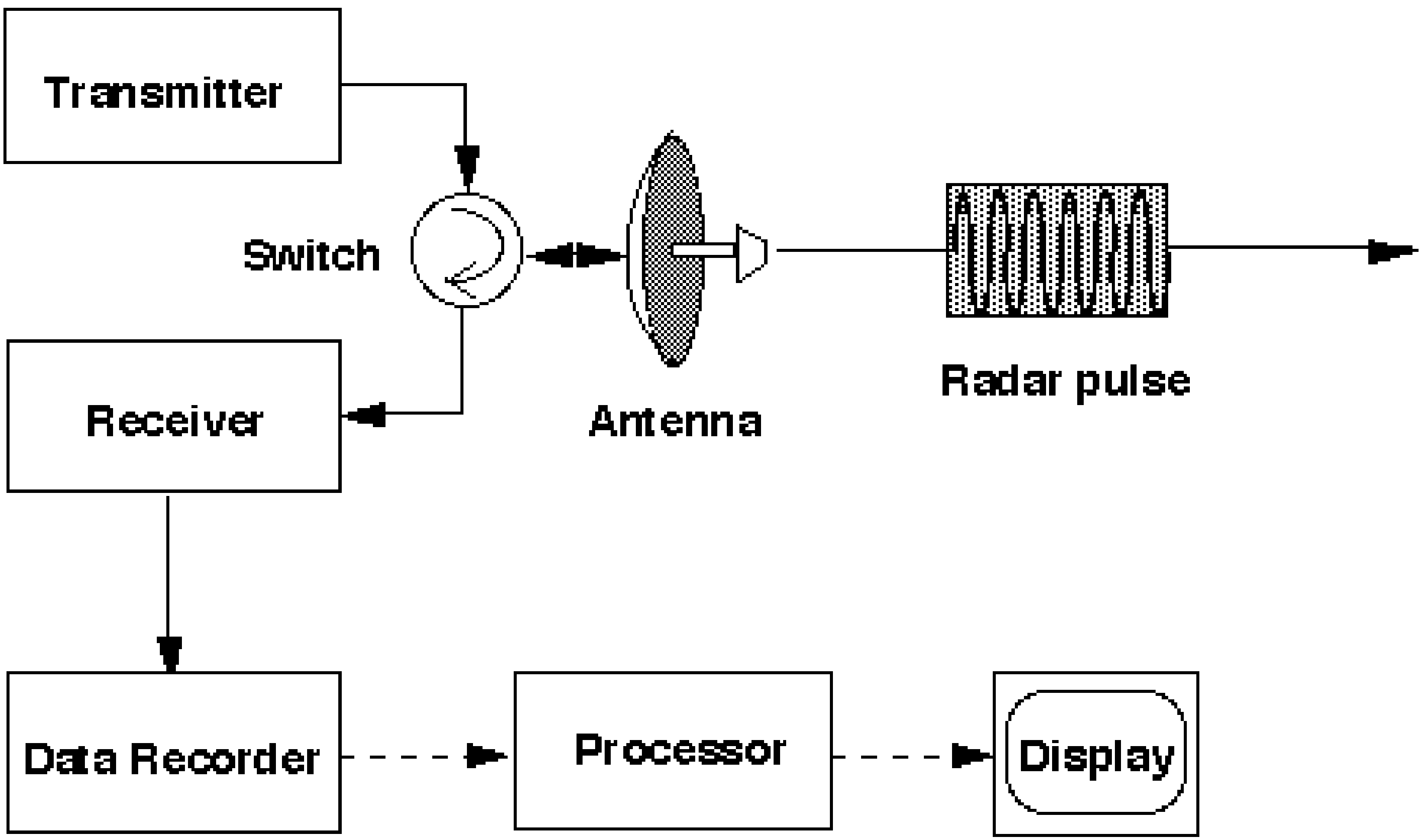
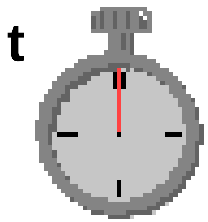
Radar Basics

- Basic radar components
- Range detection
- Radar Equation
- Speed detection
- Radiation pattern
- Types of radars

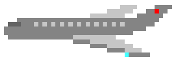
Basic Radar Components

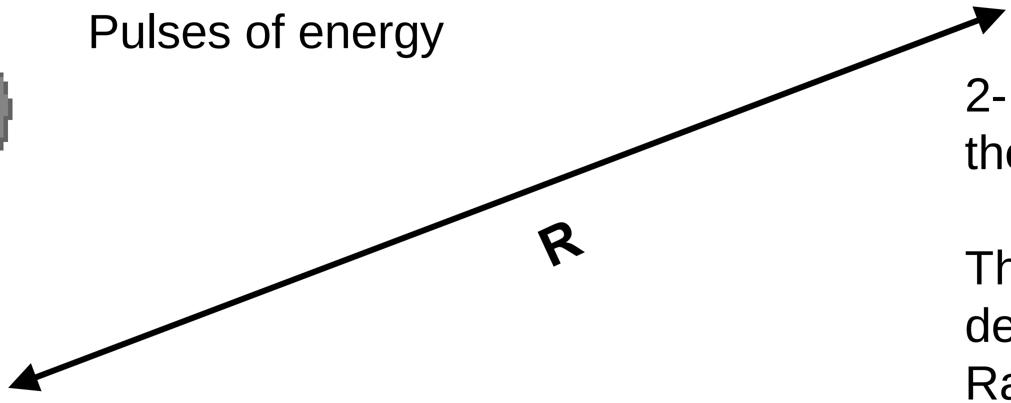


Basic Operation



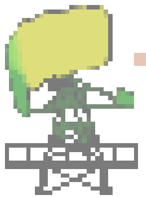
1- Radar transmit
Pulses of energy





2- Target reflects some of the energy back to radar

The reflected energy depends on the objects Radar Cross-section (RCS)



3- Radar receives the reflected signal

$$R = \frac{c\,t}{2}$$

Where ***c*** is the speed of light in free-space **(300000000 m/s)**

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Basic Radar Equaion

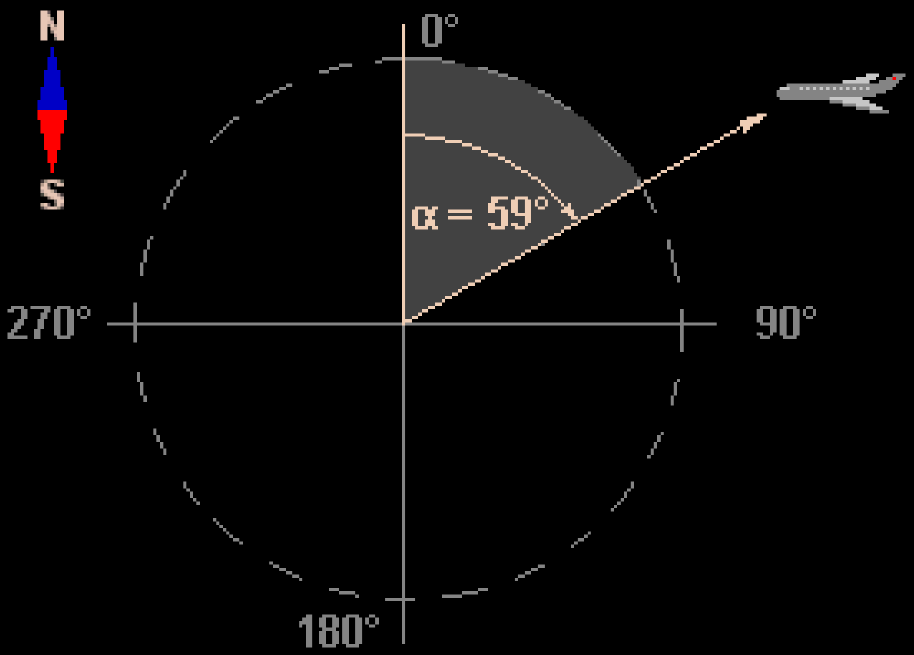
$$\text{Power received} = \frac{(\text{Tx Power})\,(\text{Tx Gain})\,(\text{Rx Gain})\,(\text{RCS})\,(\text{Wavelength})^2}{(4\,\text{PI})^3\,(\text{Range})^4}$$

Received power is dependant on:

Radar specifications: Antenna Gain, Transmitted power, Operational frequency

The targets attributes: The **range**, the target **RCS**

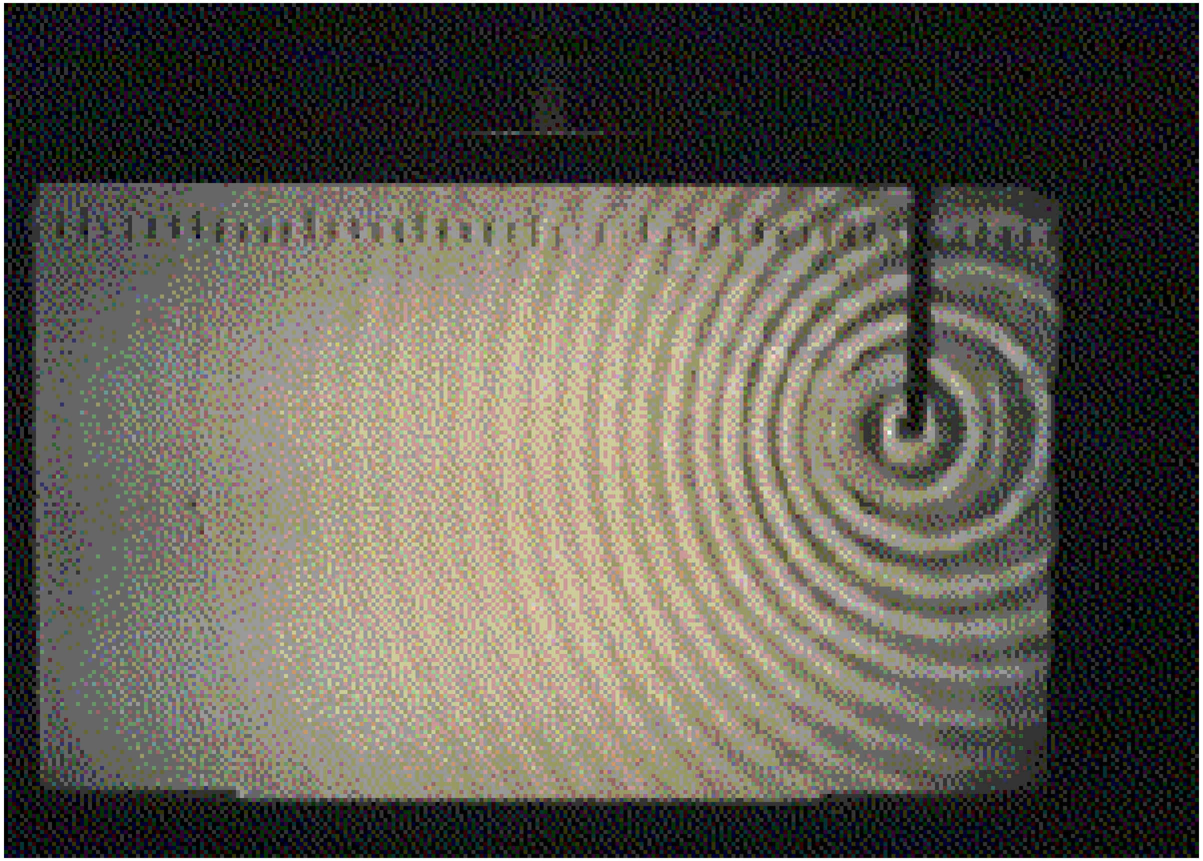
Basic Operation



Speed Measurements

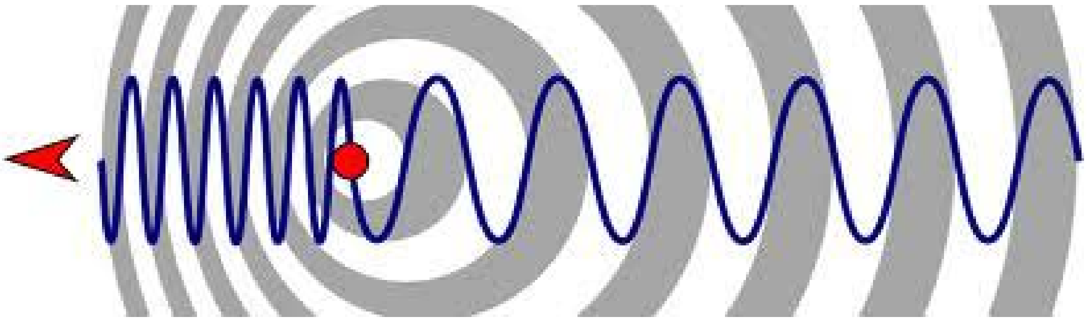
- Speed is measured using the Doppler shift
- The Doppler effect is often experienced when you listen to a car driving past with the car horn operating.
- The pitch (or frequency) of the sound is different for the approaching car than when it is going away
- The change in frequency is referred to as the Doppler frequency shift

Doppler Effect



Speed Measurements

- The same principle applies for electromagnetic waves.
- Any approaching target will give a radar return with a slightly higher frequency than that which was transmitted whereas any receding target will give a return at a slightly lower frequency.



Doppler Radars

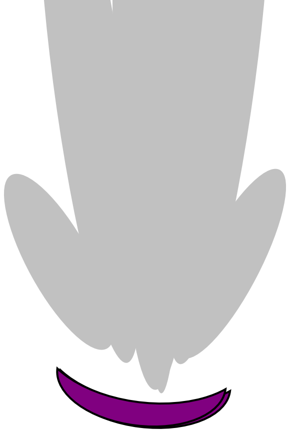
- Some radars use Doppler signature to distinguish between moving objects (such as airplanes and ships) and static objects (such as trees and buildings)
- Radar echoes from objects/surfaces that are not of interest to the radar operator are referred to as Clutter
- Clutter detection makes identifying and tracking targets a difficult task

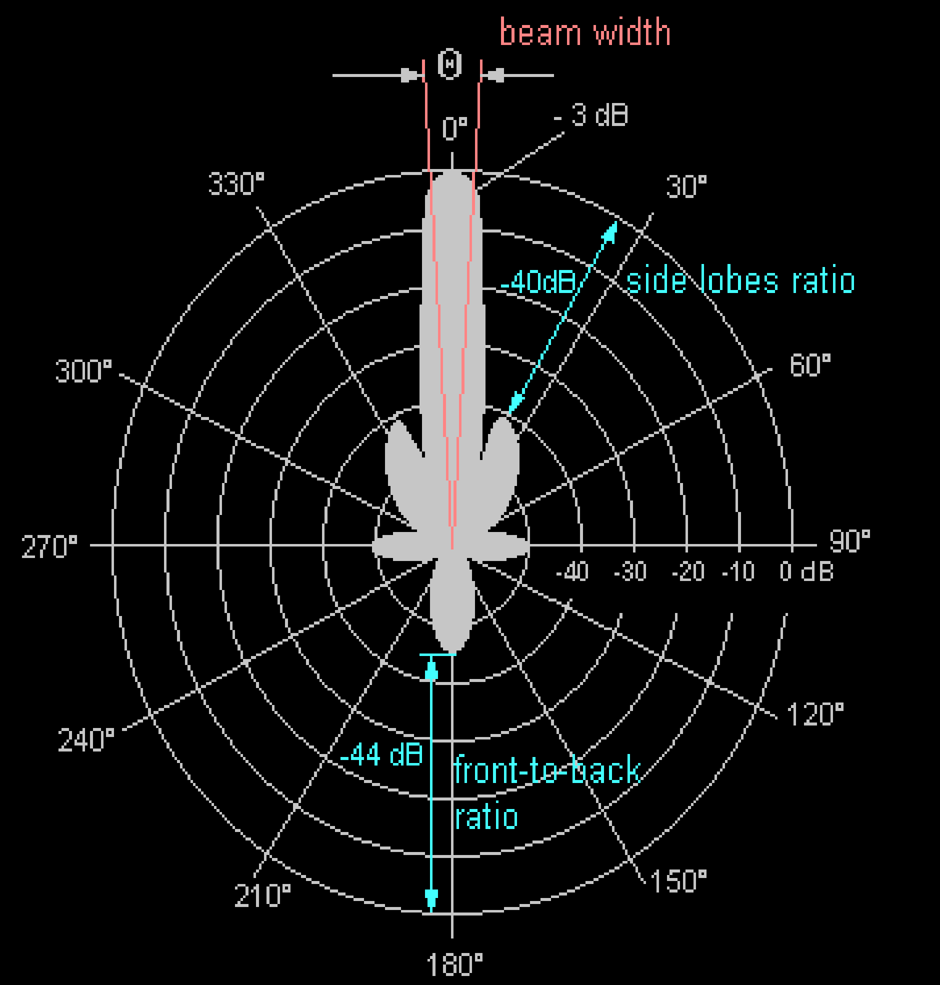
Radiation Pattern

The radar radiation pattern has a given beam width depending on the antenna

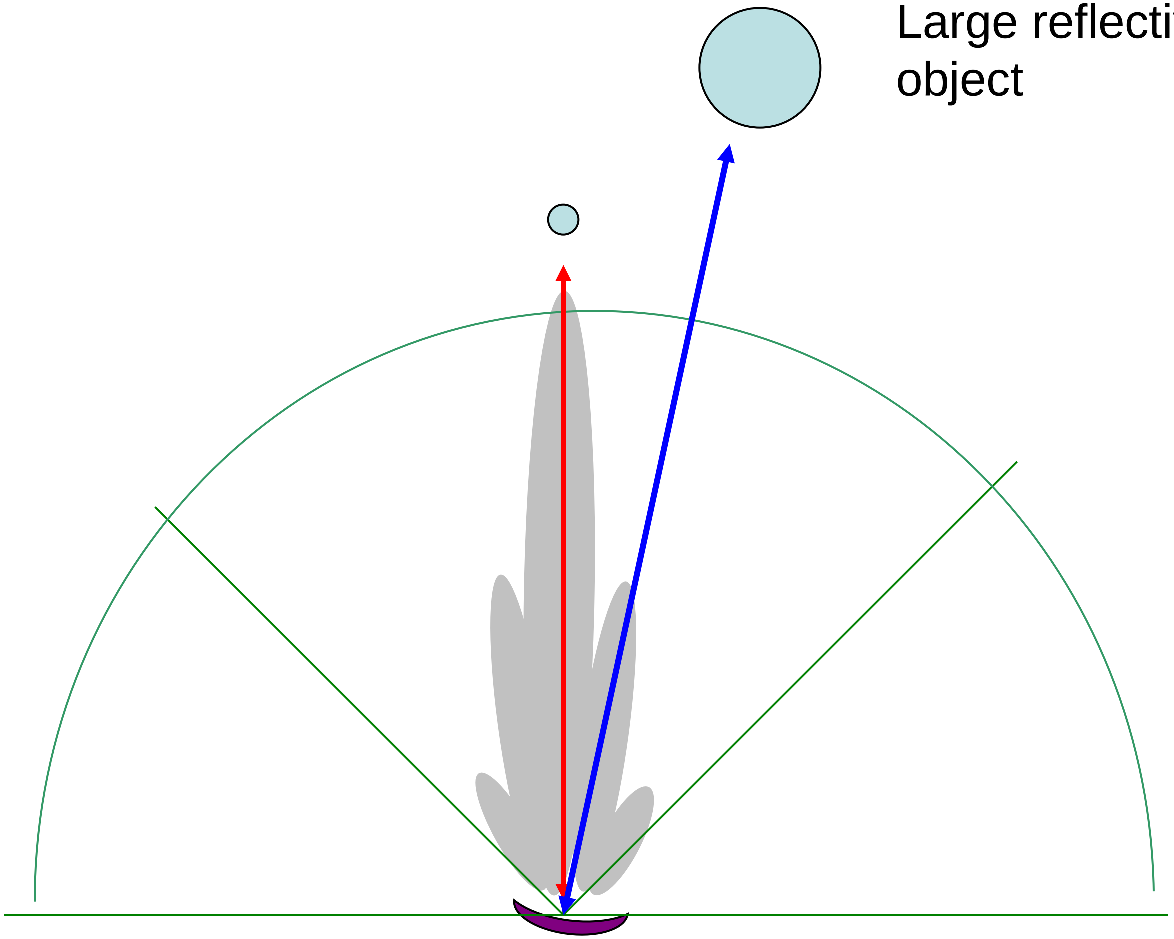
The radiation pattern also has side-lobes which transmits low energy pulse in other directions than the main beam

These beam shape imprefections cause some issues when large objects are illuminated

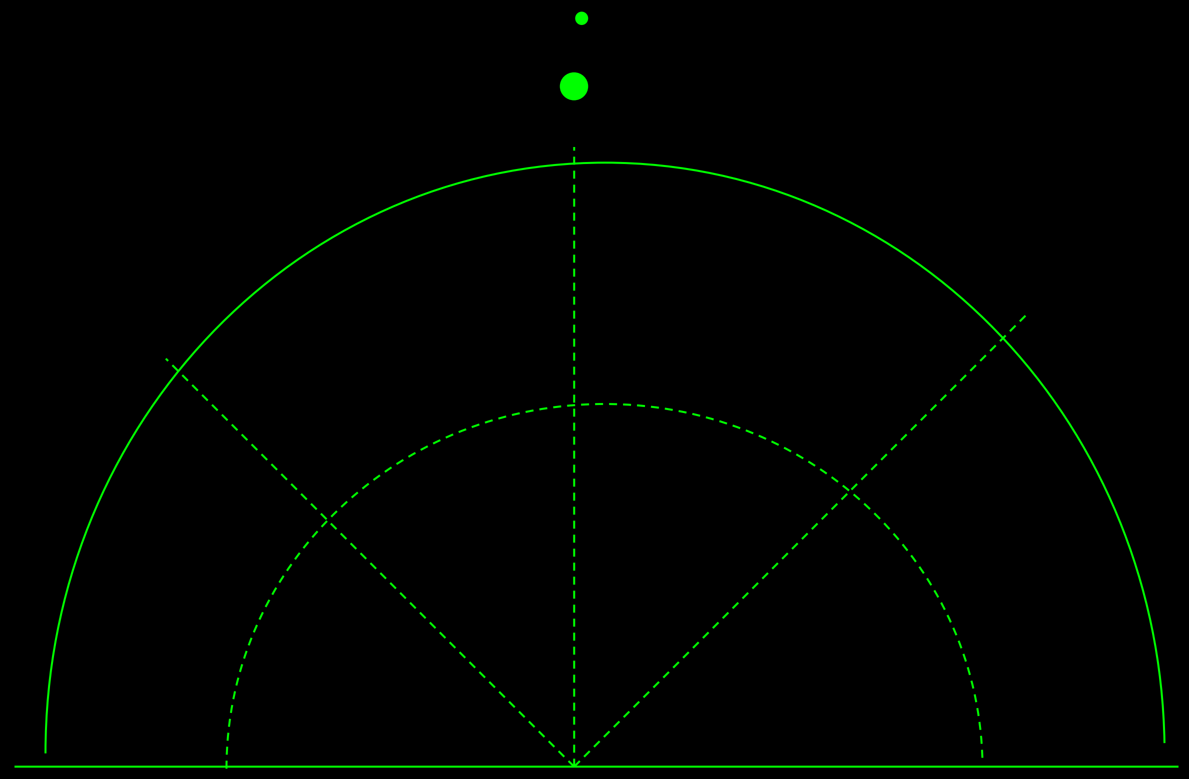




Sidelobe detection

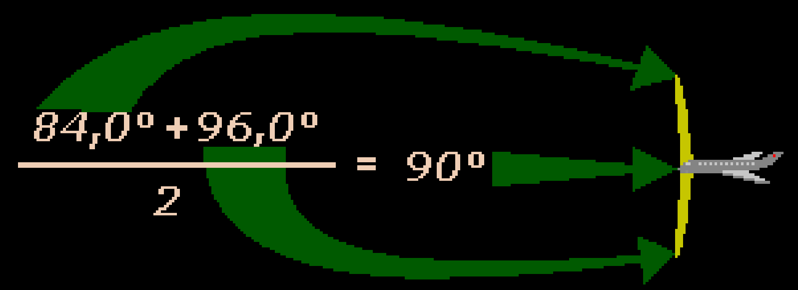


Sidelobe detection

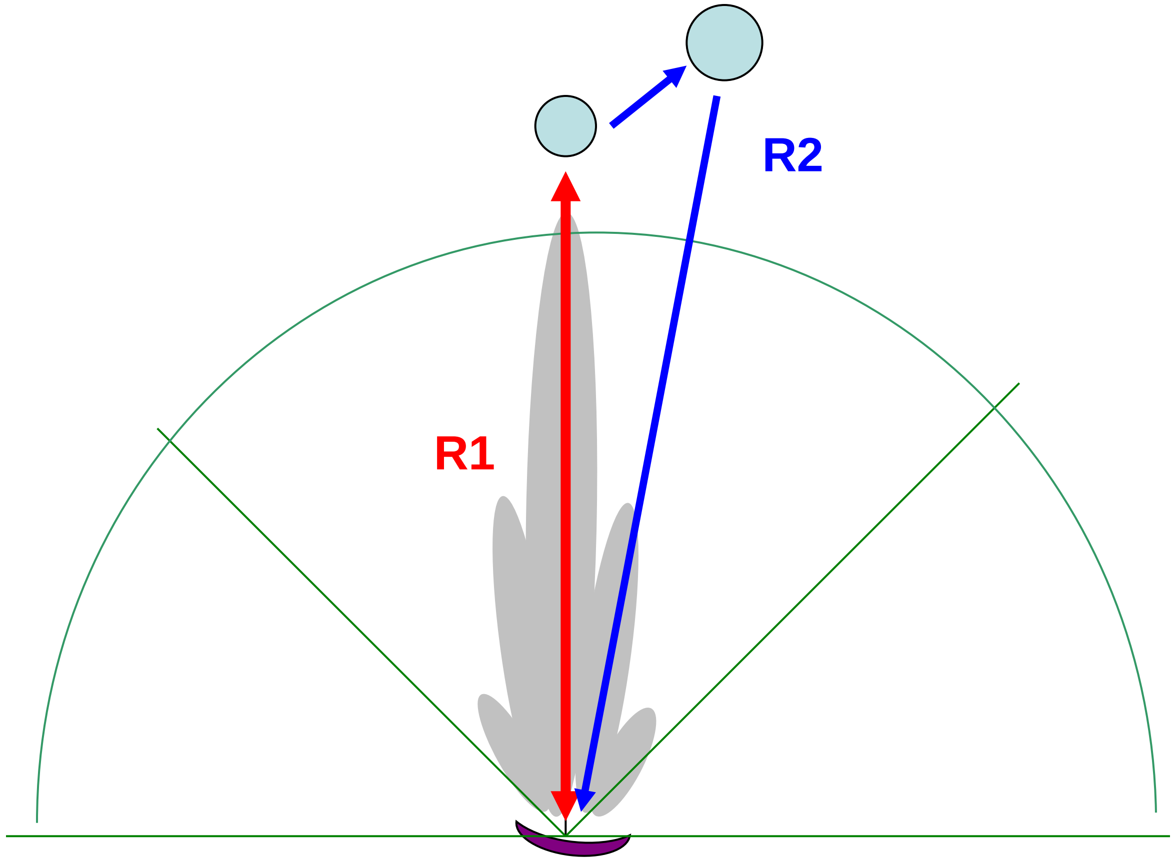


Target Spreading

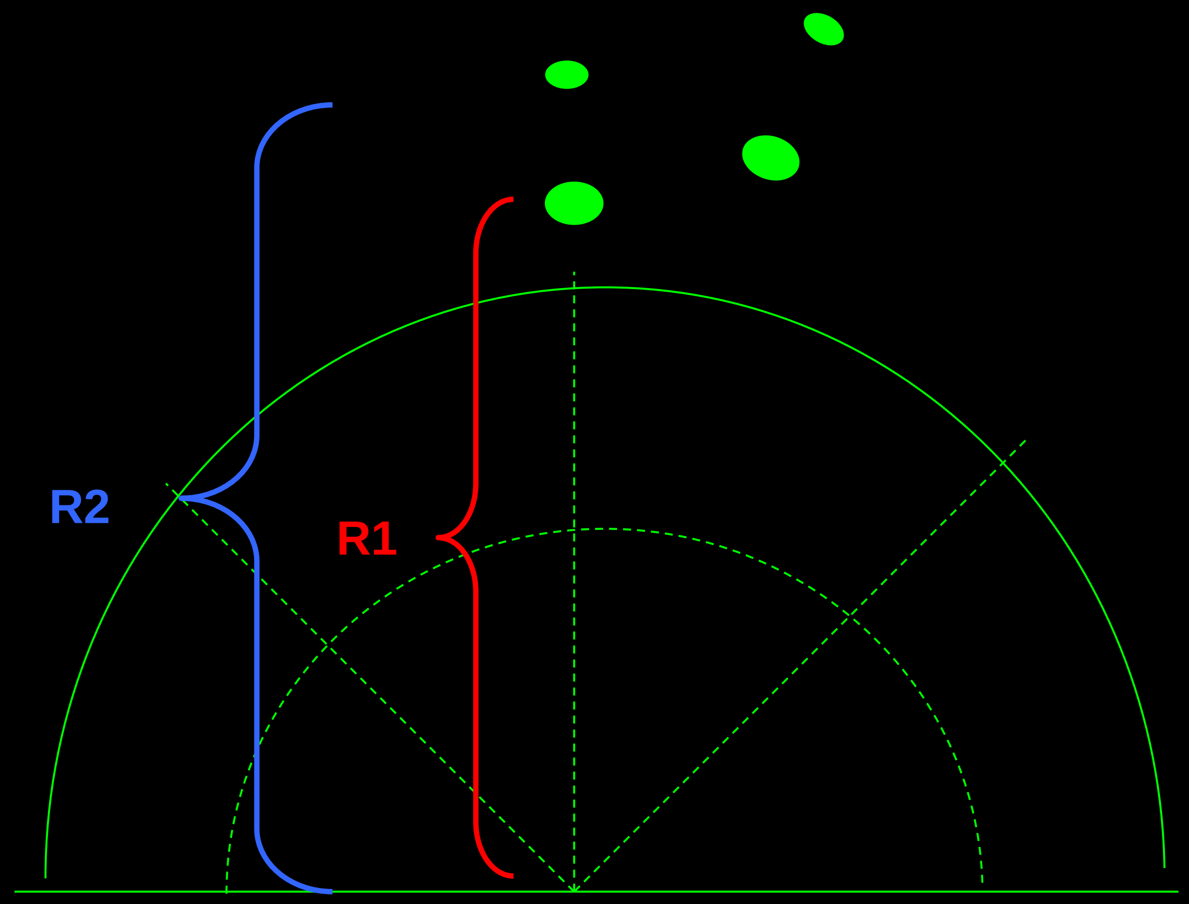
- When the object is large and relatively far away, it is detected across the whole beam-width.
- This would make the target appear as a widened blub on the screen



Multiple Reflections



Multiple Reflections



Types Of Radars

Wind Farm Effects on Radar

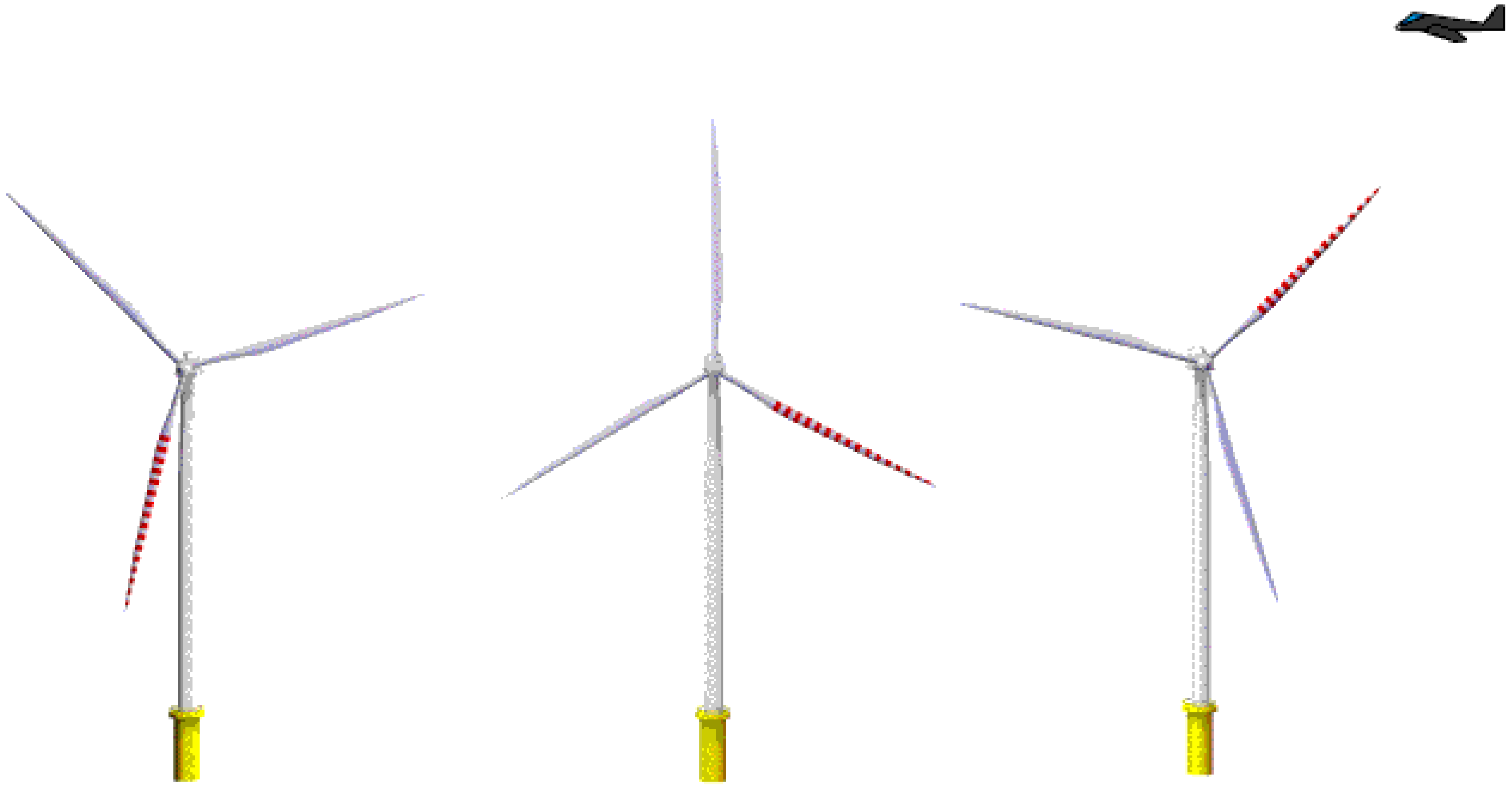
- **The Defence Community**: The turbines may interfere with air defence radars due to the Doppler signature of the blade and the large Radar Cross Section (RCS) of the turbines.
- **ATC (Air Traffic Control):** similar to the above, which may lead to false target tracking (twinkling) and/or target track seduction
- **Maritime Agencies**: large RCS causes potential Rx limiting, the appearance of false targets, target spreading and sidelobe detection.
- **The Met Office**: the presence of turbine blades will alter the returns from precipitation, while the presence of towers will block the radar signals from travelling to the specified range.

Types of Radars Considered

- **Marine radars** don't normally use Doppler
  - Complex equipment and processing
  - Waves can run faster than ships!

- **Air Traffic Control radars** do use Doppler as aircraft can move quickly
  - unfortunately so do wind turbine blades

Blade tips vs air targets



Wind Farm Effects on Radar

- Effects on marine radars   (Supergen Phase 1)
  - Ghost targets
  - Side-lobe detections
  - Shadowing
  - Receiver limiting
- Effects on ACT and AD radars
  - Twinkling effect
  - Track seduction
  - False track initiation
  - shadowing

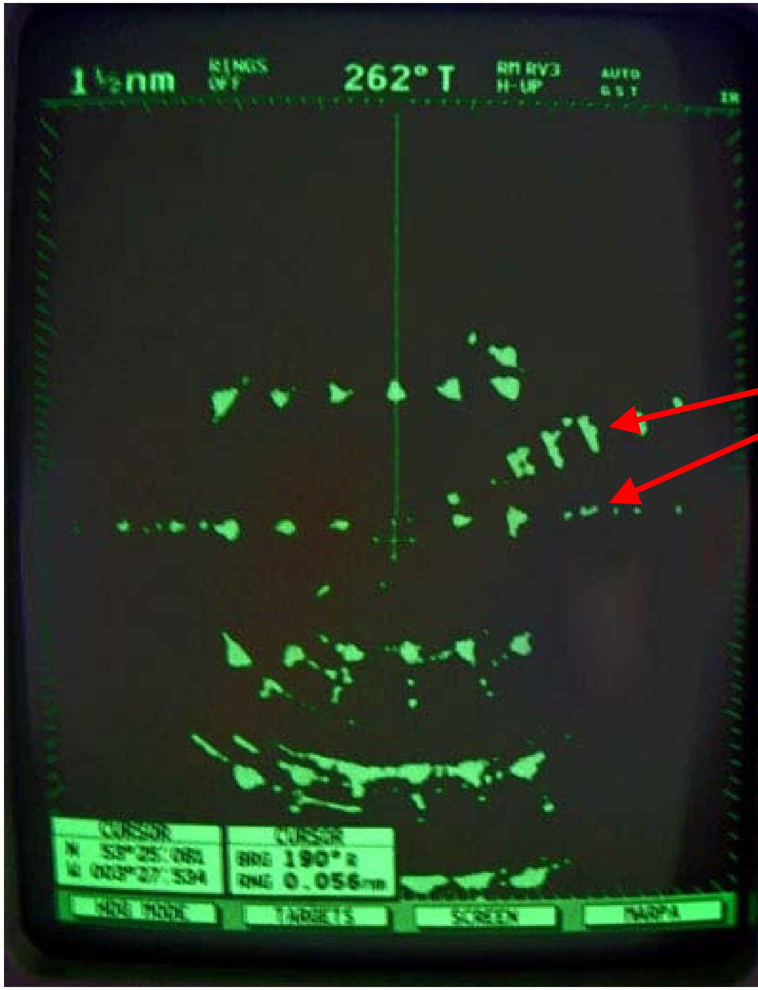
Measured Data

Target Spreading causing difficulties to identify targets within the wind farm

Measured Data

Mirror image of the wind farm due to reflection of radar signals off the ship's superstructure

Measured Data



False (ghost) targets appearing on display due to multiple reflection within the wind farm

Measured Data

Turbine is not visible due to shadowing

Simulator Requirement

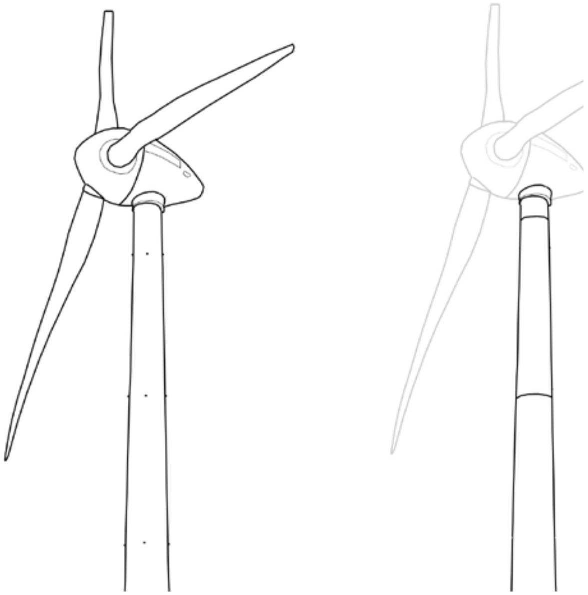
- A simulator is needed to model the effect on radars before the construction of a wind-farm, such that the effects of different turbine design and farm layouts can be considered
- Wind-farms can be large and complex, however we need a fast computation time, regardless of the physical size of the wind-farm, hence an **approximate** model is needed

Supergen – Phase 1

- In Supergen Phase 1
  - The impact of wind farms on marine radars was simulated
  - RCS models were developed to calculate the static RCS of the blades, nacelle and tower
  - Effects such as multiple reflections, target spreading, shadowing and side-lobe detections were successfully modelled
  - The developed models gave accurate results in a computationally efficient manner

Approach – Tower Modelling

- The tower is the largest component of the turbine
- Details such as rails, doors, lights and joints/bolts were removed from the CAD model in order to enhance the RCS computation speed
- The tower is now modelled as a set of cylindrical sections with varying taper
- The RCS of each cylinder is then calculated to model the energy reflected around the tower
- The total RCS of tower is then calculated by adding the RCS of individual cylinders

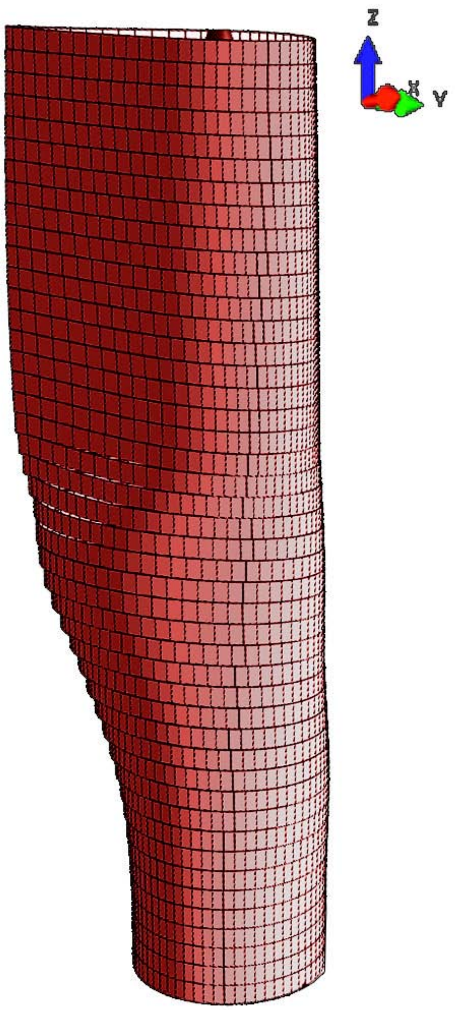


Approach – Blade and nacelle modelling

- The blades and nacelle are complex shapes with combination of flat areas and curved surfaces
- The RCS is highly dependant on the geometry of the blades and nacelle, therefore using simplified shapes will give inaccurate results
- However, traditional modelling techniques of such large objects will require large computing resources
- New modelling approach was developed to rapidly calculate the RCS of blades and nacelle

Approach – Blade and nacelle modelling

- The blade is meshed using a rectangular mesh points along the length of the blade (facets)
- The RCS of each facet is calculated using simplified Physical Optics formulations
- The total RCS of the blade then obtained by coherently adding the contribution from each facet



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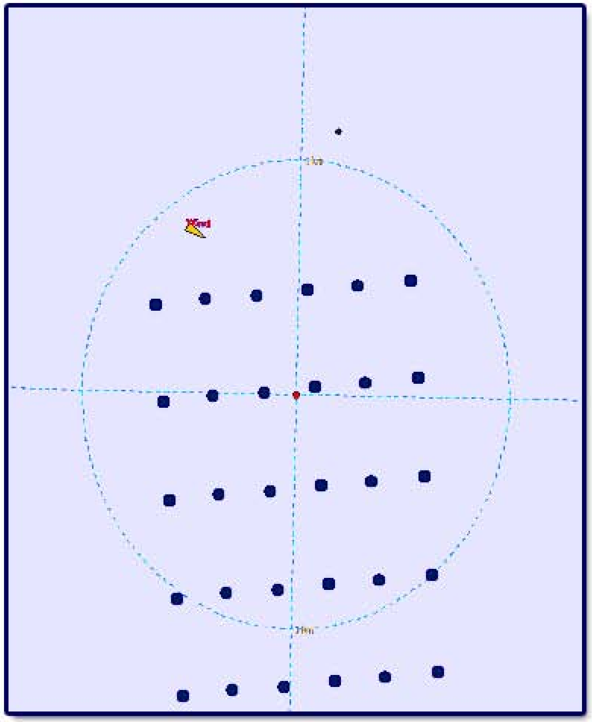
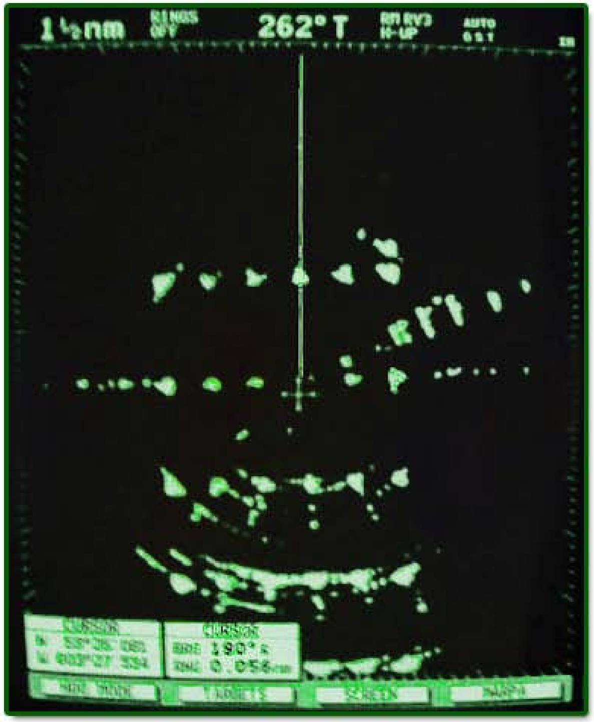
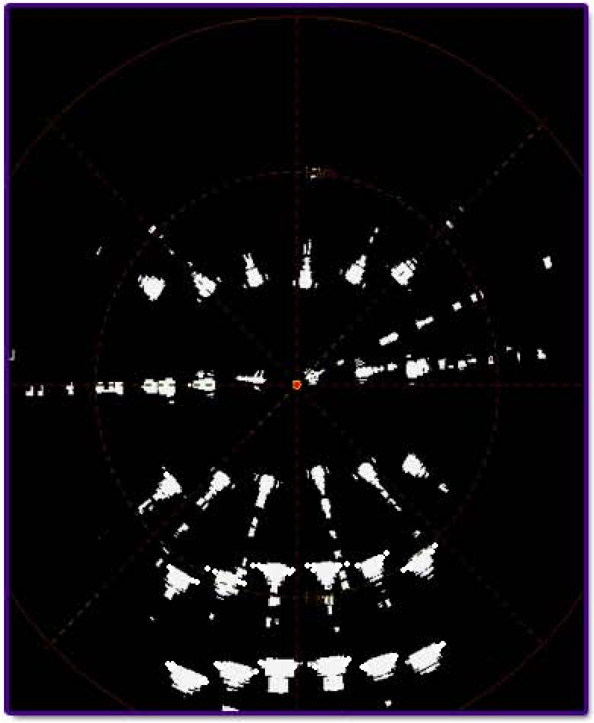
Complete Turbine

Wind farm impact modelling







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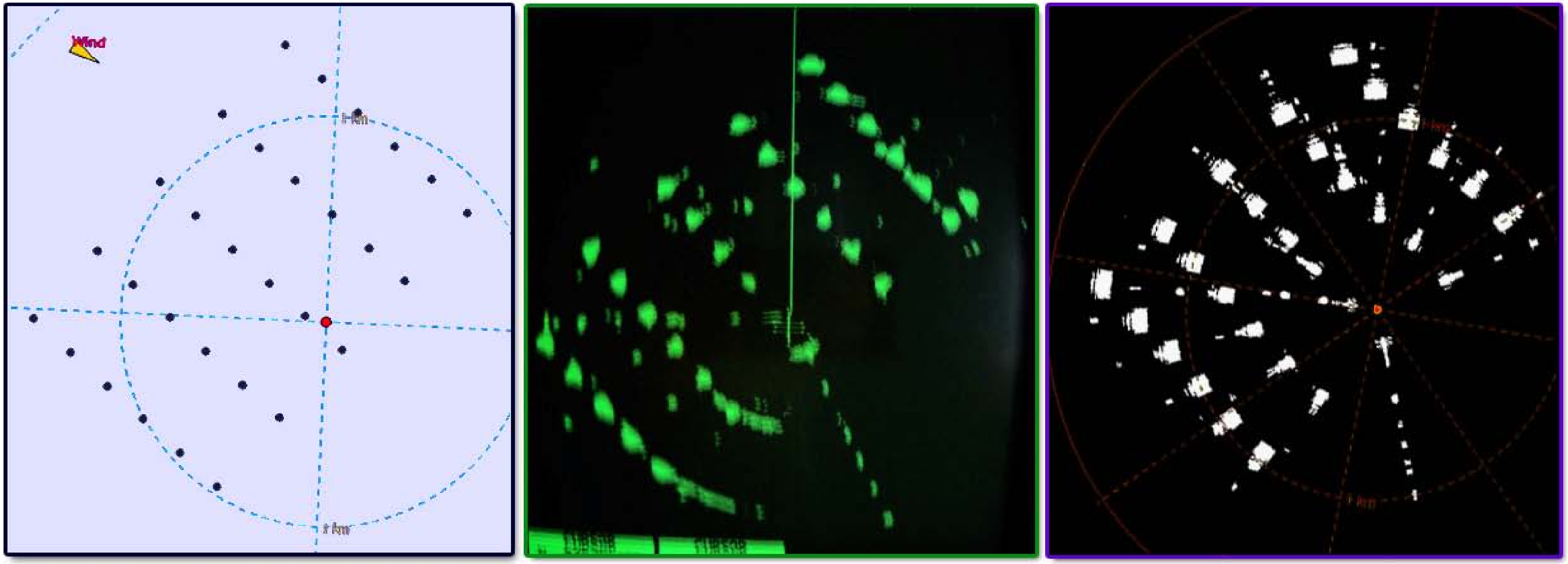
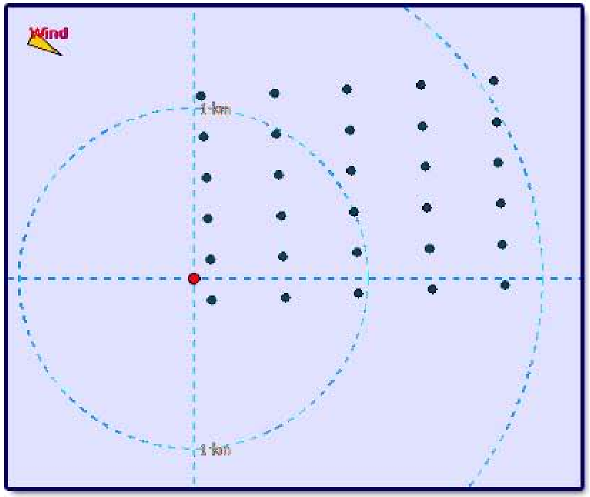
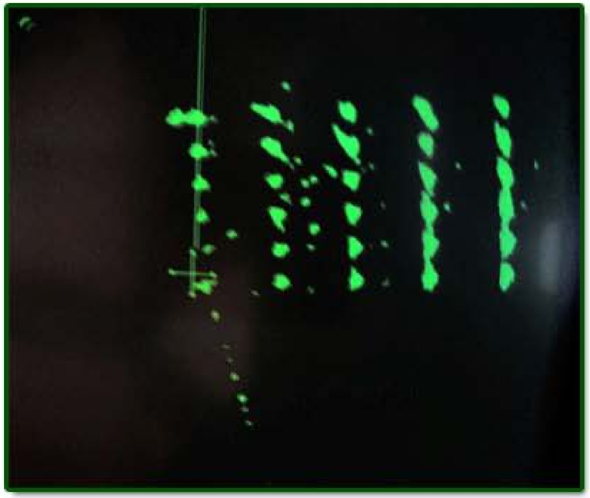
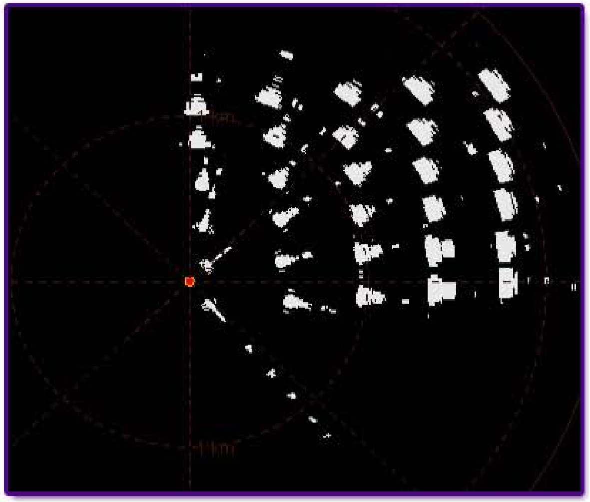
Wind farm impact modelling



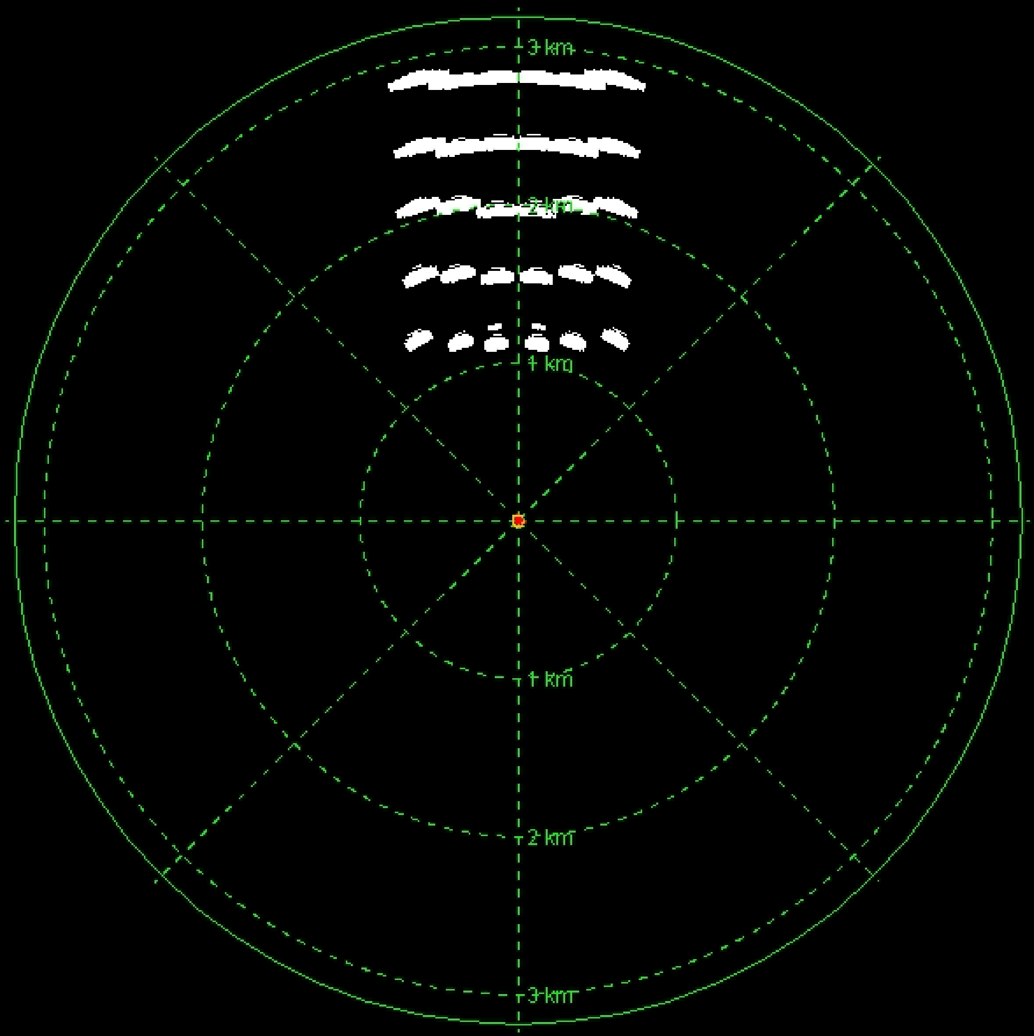
Wind farm impact modelling







Scenario Modelling : Sailing Through



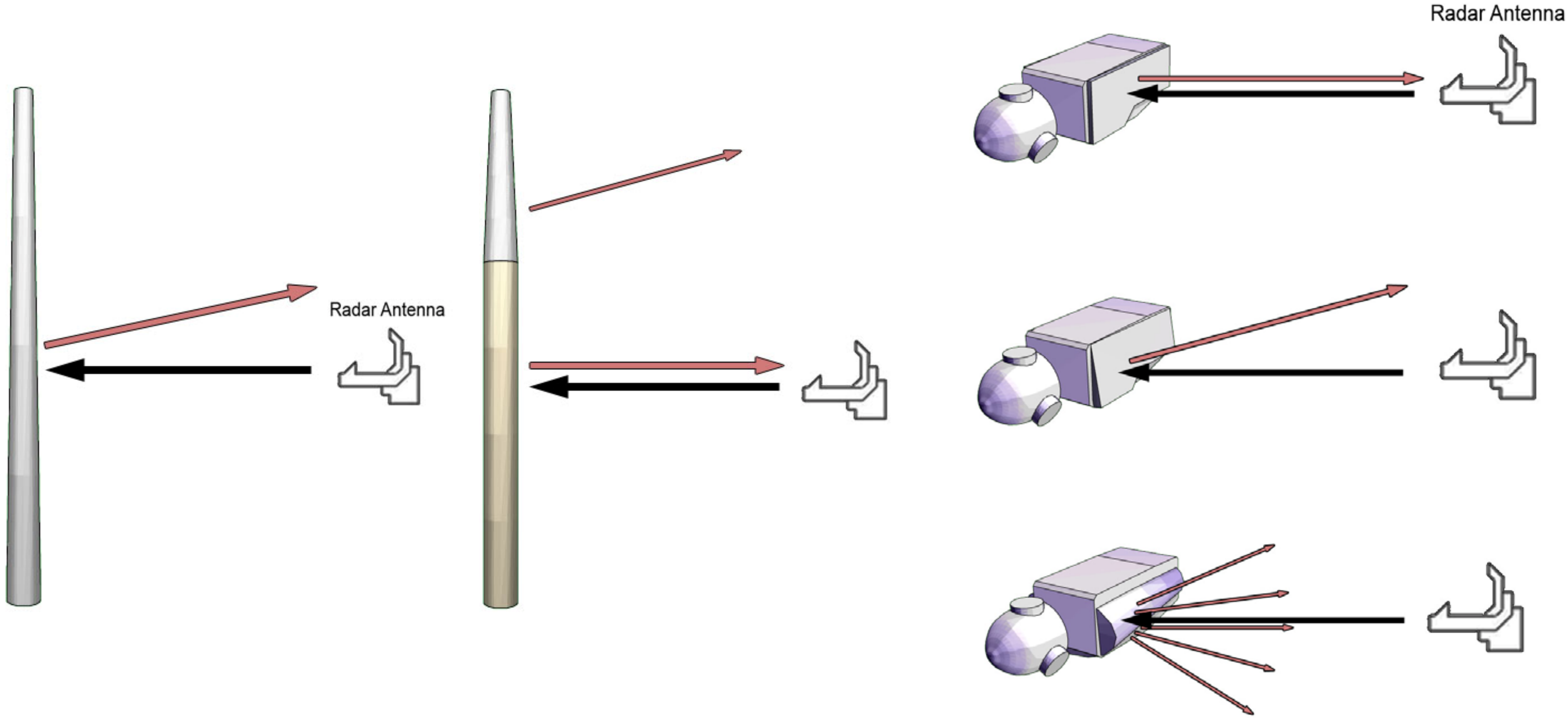
Turbine RCS reduction

- Most of the problems arsing from wind farms arises from the large reflection generated by the turbines
- The shape, size and material of turbines makes the RCS very large compared to other targets of interest
- Clutter suppression techniques and advanced digital tracking may reduce the effects of wind turbines on radars that use Doppler processing
- However, not all radar systems are equipped with Doppler processing or have advanced signal processing algorithms
- So, where it is possible, the RCS of turbines must be reduced

Mitigation through Stealth

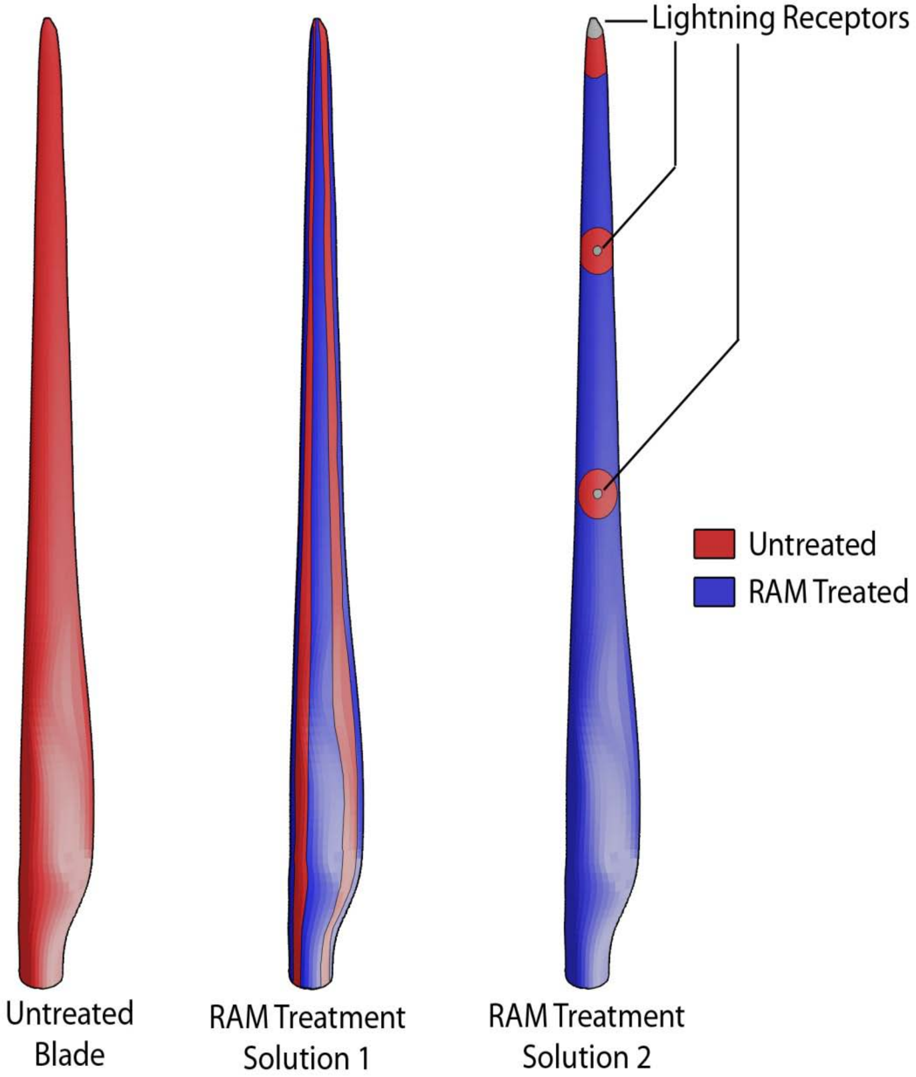
- The RCS of the tower and nacelle can be reduced by shaping
- RCS can be reduced significantly by tapering the tower and by using curved/tilted surfaces on the nacelle
- The blades can not be shaped as it is carefully designed for maximum efficiency and aerodynamic
- Applying stealth/Radar Absorbing Materials (RAM) is a possibility to reduce blade RCS
- RAM solution must be light-weight and compact to avoid changes to the blade profile and adding excessive weight penalties

Tower and nacelle shaping



Stealth and Lightning Protection

- In order to have a compact RAM solution, the RAM design must be placed over a thin conducting ground plane (mesh or foil)
- Such RAM solutions used on the blade may effect the lightning protection system and vice-versa
- Close collaboration with the high-voltage research team is needed to reach a practical solution
  - Different solutions for different parts of the blade?
  - Altering the existing lightning protection system?
  - Materials?



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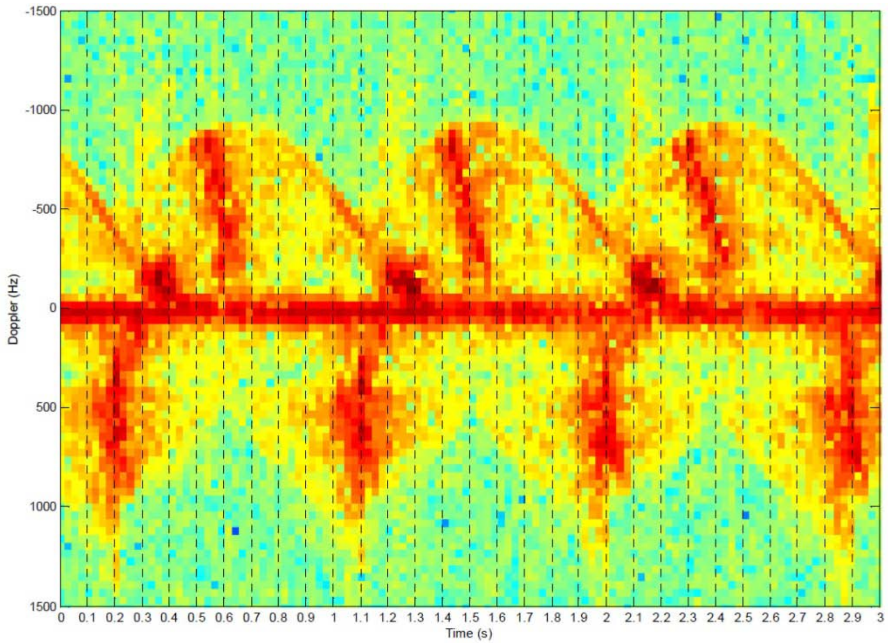
Next Seminar

- Air Traffic Control (ATC) radars
- Effects of wind farms on ATC radars
- Doppler signature of wind turbines



Multiple reflections from cliffs

- Interaction of terrain with reflections from wind turbines
- The use of multiple radars to mitigate the impact of wind farms