



Wind Farm Mitigation Using New Alternatives to Radar

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Rationale



Rationale:

- Wind farms are an important source of renewable energy
- It is known that large turbines have an adverse effect on primary and secondary surveillance radars
- Alternatives to PSR and SSR are MSPSR and WAM

Questions:

- What are the impact mechanisms?
- How serious is the interference?
- How to mitigate the interference?



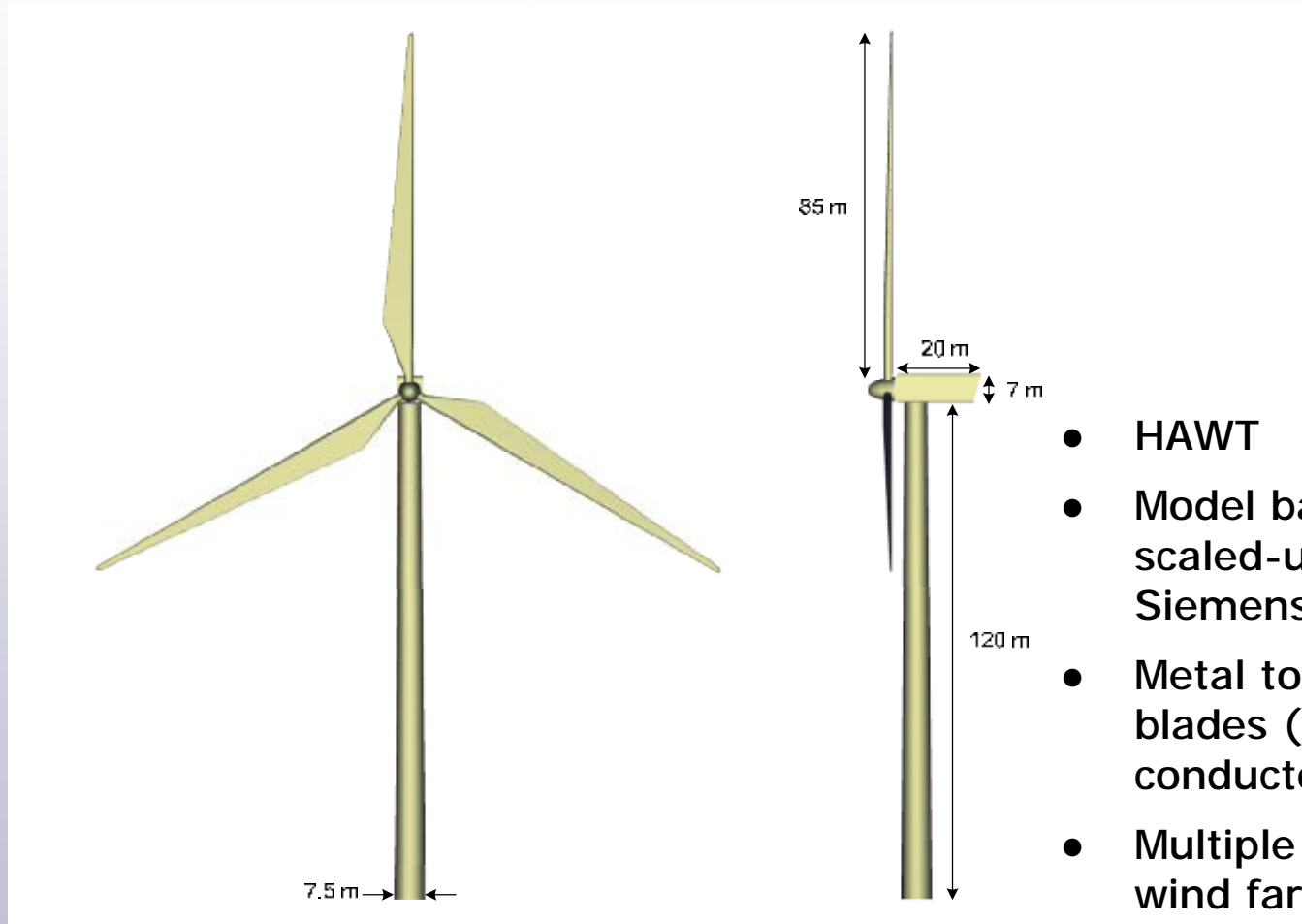
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Wind Turbine



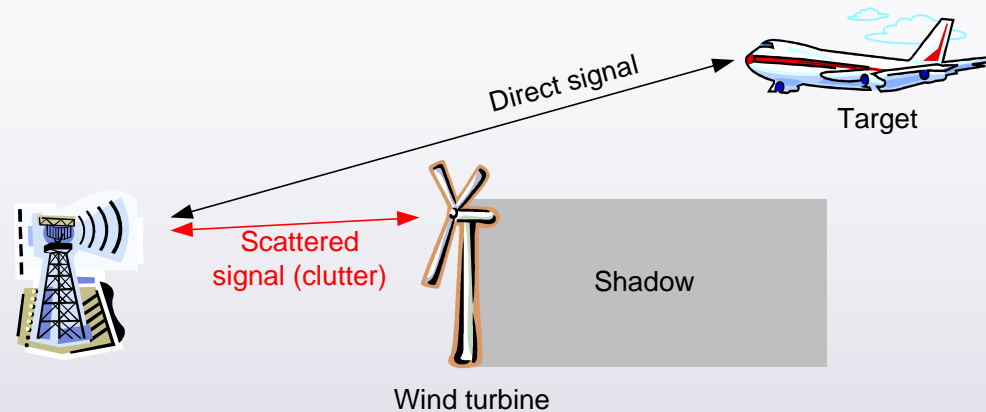
- HAWT
- Model based on the scaled-up largest Siemens turbine
- Metal tower, composite blades (with lightning conductors)
- Multiple turbines in a wind farm

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PSR and Wind Farms



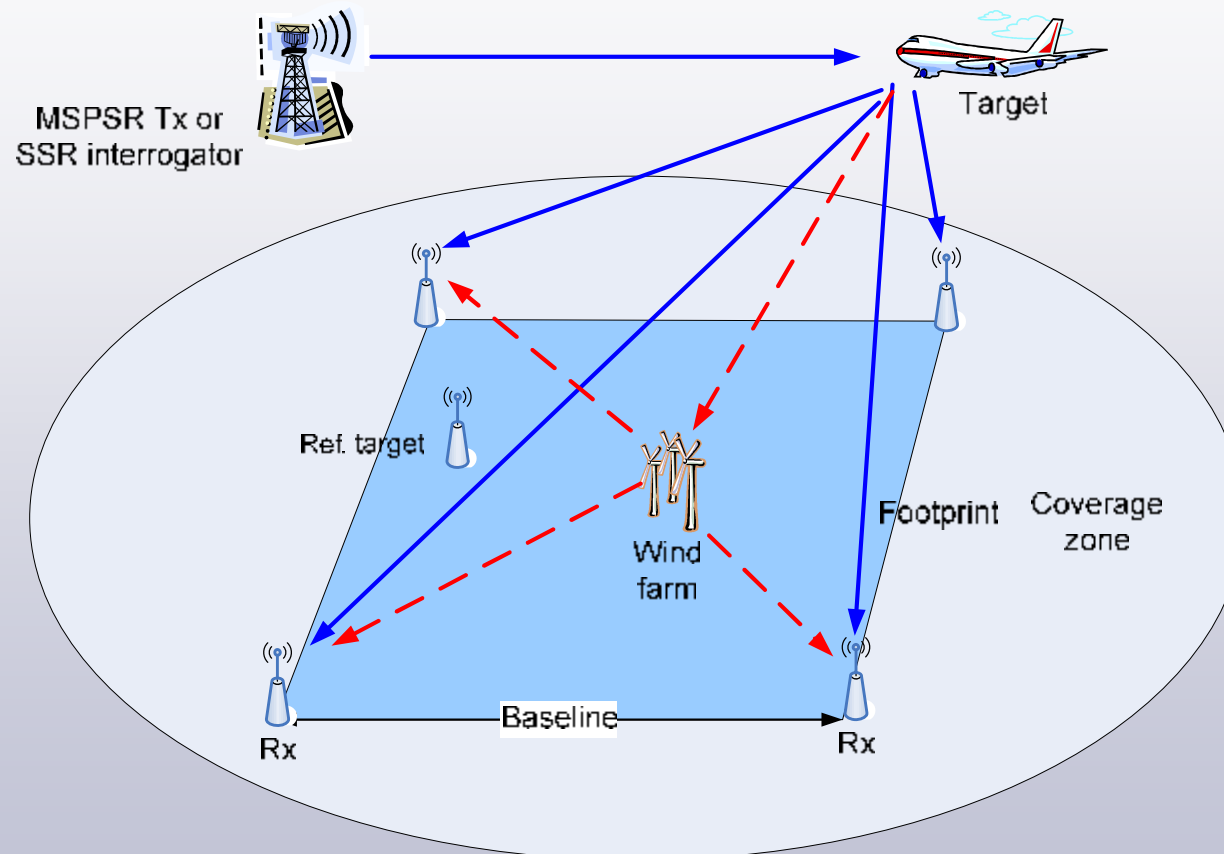
- Loss of target due to shadowing
- Dynamic clutter of wind turbines
- False targets
- Signal corruption
- Target range, azimuth and height errors
- Tracking errors (e.g. false track initiation)
- ...

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MSPSR, WAM and Wind Farms

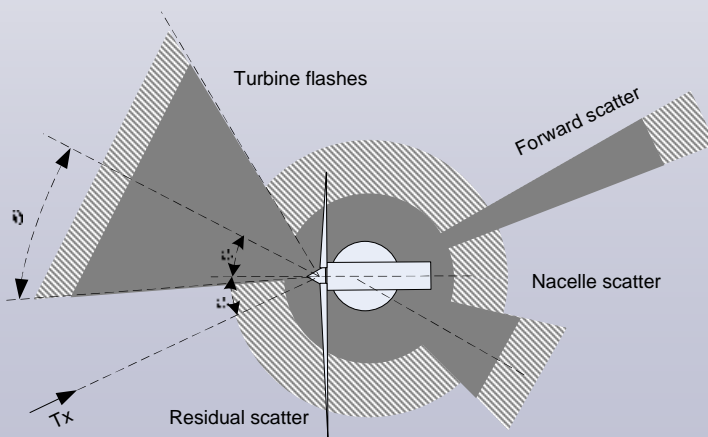
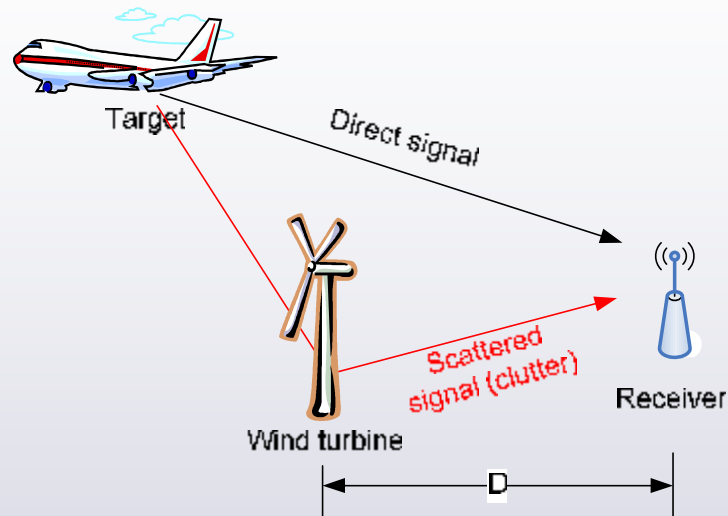


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Scattering



- Scattered power can be calculated from bi-static Radar Cross Section (RCS) and radar equation
- In multistatic systems, geometries causing worst reflections can potentially be avoided
- Directions of strongest scatter can be predicted using Snell's law, or an RCS prediction software

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Prediction of Scattering

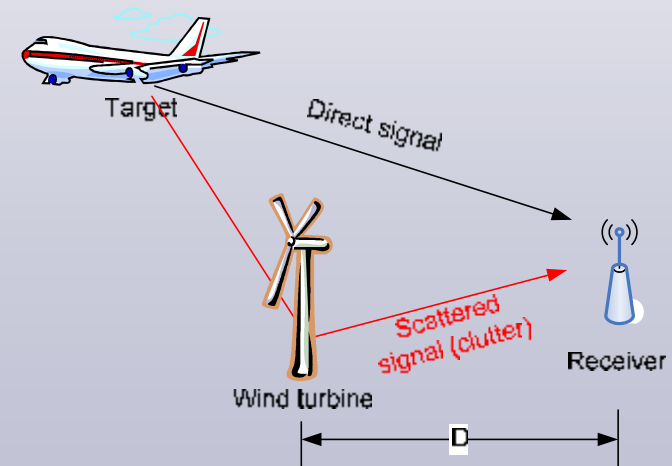
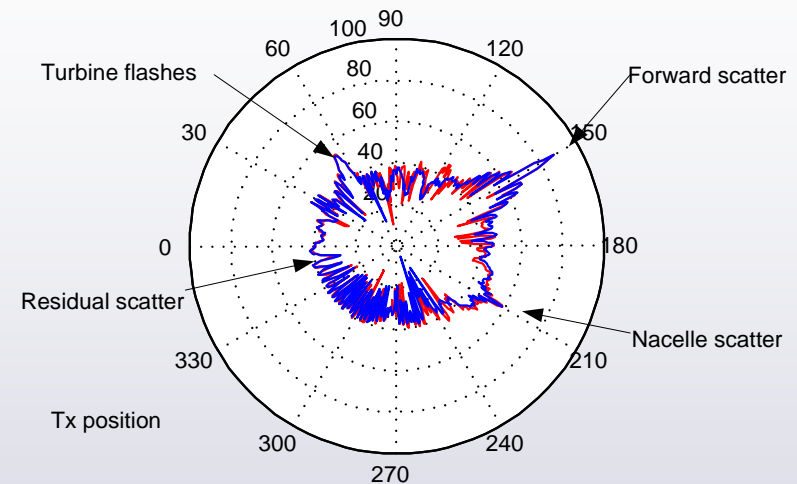


RCS predictions made with Epsilon™:

- Around 53 dBsm for strongest flashes;
- 40 dBsm or less in most other directions.

Direct / scattered signal of 30 dB:

- 53 dBsm of strongest turbine flashes $\rightarrow D = 4$ km
- 40 dBsm or less in most other directions $\rightarrow D = 1$ km

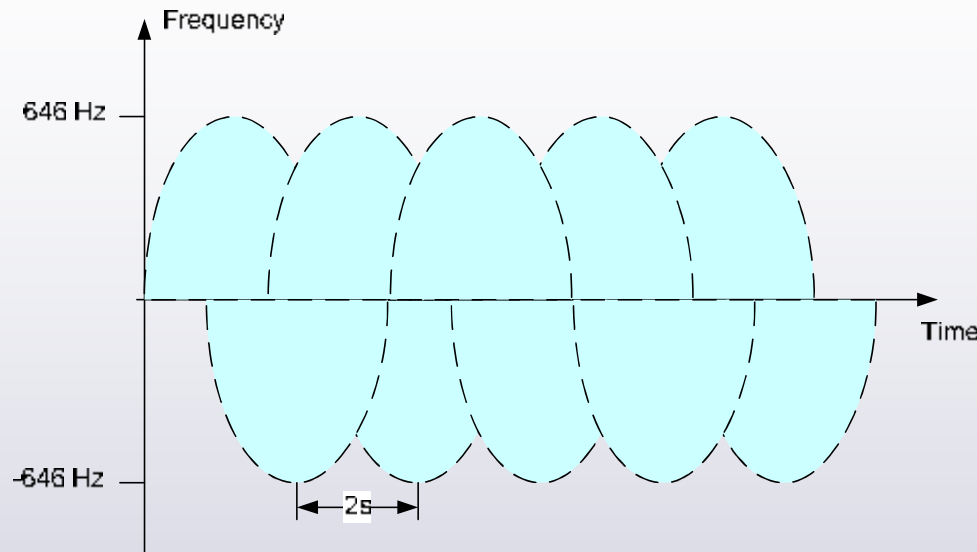


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Doppler



$$f_D = \frac{2V}{I} \cos(d) \cos(b/2)$$

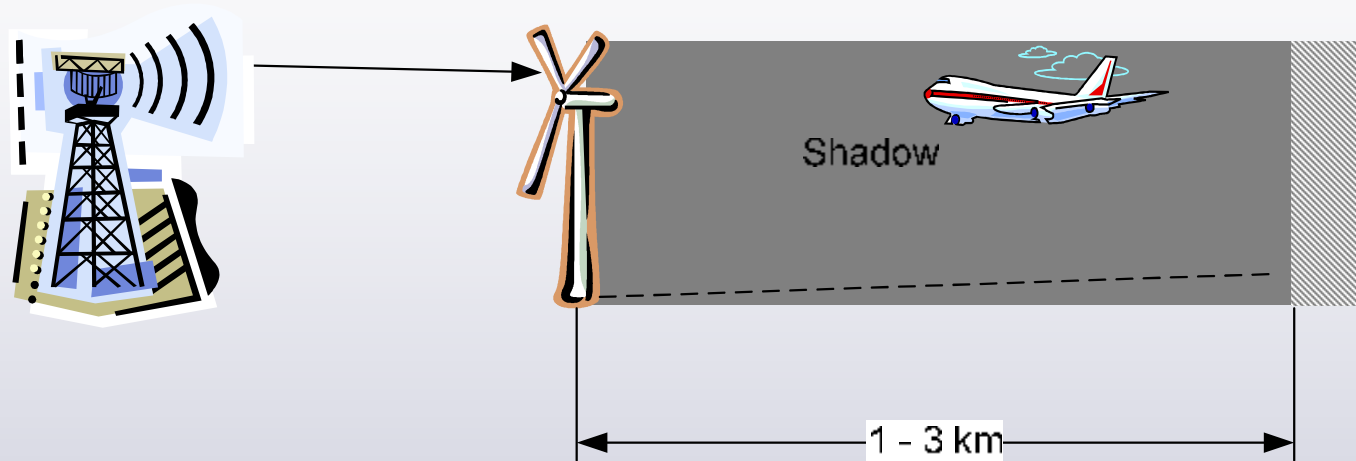
- Blade rotation → Doppler shift in any reflected signal
- Doppler is spread between 0 and $\pm f_{Dmax}$
- $f_{Dmax} = 646.7$ Hz for the Tx and Rx co-located
- In MSPSR, Doppler spread can be lower due to the geometry
- WAM does not use Doppler processing → no impact expected

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Shadowing



- Up to 2 deg wide wedge
- For each Tx in the system there is a shadow behind each turbine
- In a multistatic system, all receivers will not shadowed simultaneously

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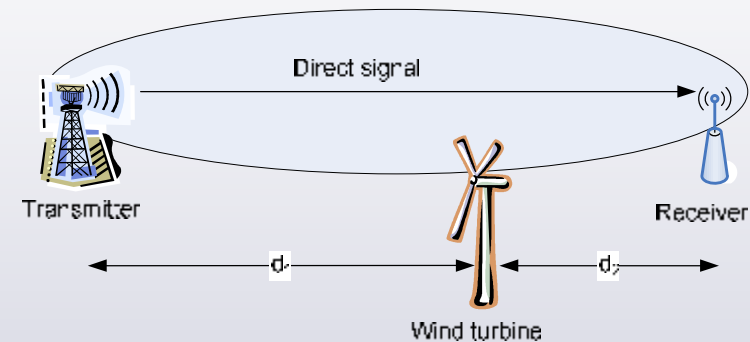
1st Fresnel Zone



An ellipsoid with Tx and Rx in its focal points

Should be clean of obstacles
(obstacle in the 1st Fresnel zone leads to all kinds of unwanted effects: signal loss, multipath, wavefront distortion...)

On frequencies of interest, 1st Fresnel zone is narrow (e.g. max diameter around 100m)



$$r_{F1} = \sqrt{\frac{1 d_1 d_2}{d_1 + d_2}}$$

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Summary on Vulnerability



MSPSR vs. PSR

- Multiple Tx and Rx: a number of simultaneous detection opportunities
- 3-D operation: target can be separated from the wind turbines
- Omni-directional antenna: much higher update rate
- Continuous, spread spectrum waveforms: use of tracking loops
- Potential gap filler for PSR

WAM vs. SSR

- Multiple Tx and Rx, no Doppler processing
- Adverse effects no different from other large structures
- Effects are transitory and limited to close range
- False targets (if any) will appear in the wind farm
- Potential gap filler for SSR

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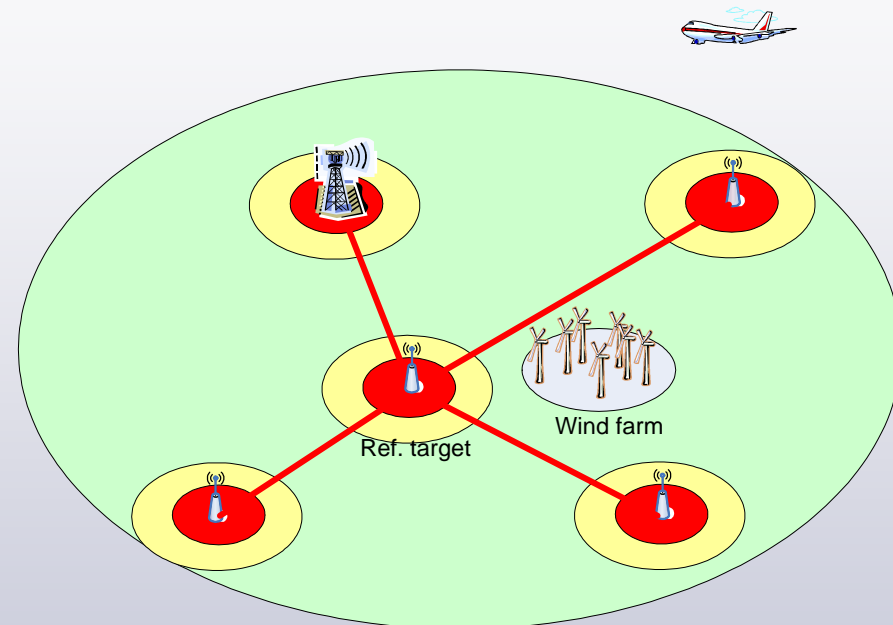
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Protection Measures

Negative effects can be avoided through an introduction of safeguarding zones:

- **Exclusion zone**, within which no wind turbine should be placed;
- **Zone of interest**, within which site analysis and/or trials may be required;
- **Zone of no impact**.
- **1st Fresnel zone** of critical links should be unobstructed; this should be assessed even within the zone of no impact.
- Additional measures: antenna beam shaping, additional Rx or Tx, multi-ranging



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