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RCS Reduction of Wind-Turbine Blades

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Defense Systems & Assessments Division

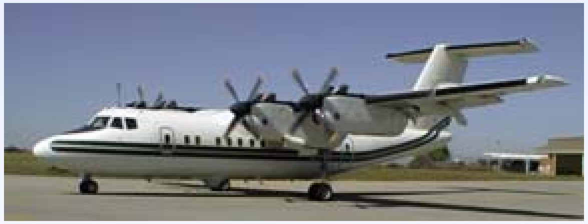
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Who we are: SAR Sensor Technologies Department

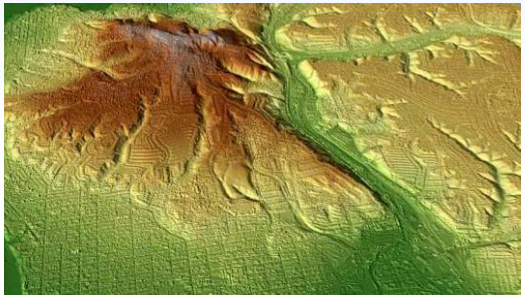
What we do:

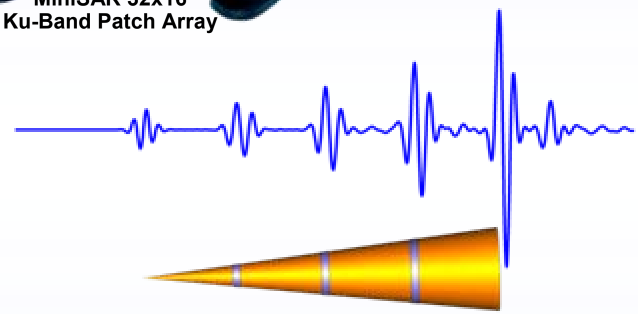
Synthetic-aperture radar
Electromagnetic analysis
Antenna design
Antenna-pattern measurement
Radar-cross-section analysis, modification, and design
Radar-cross-section measurement

MiniSAR 32x16
Ku-Band Patch Array



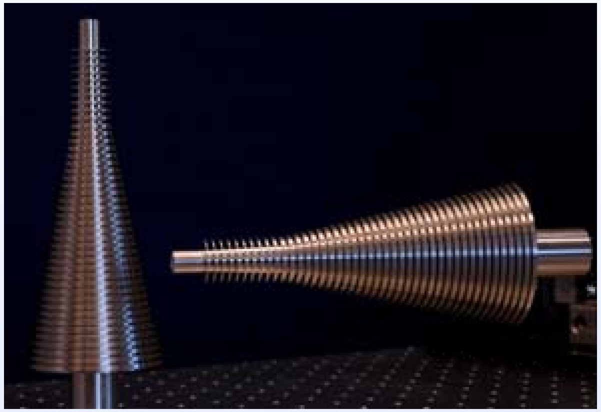
Three-dimensional imaging with interferometric SAR

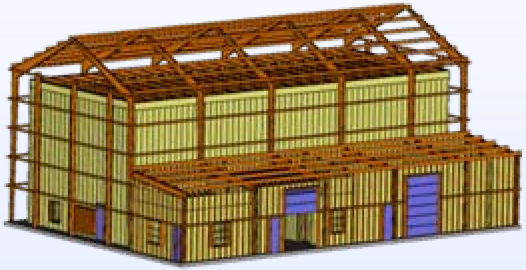




RCS computations for complex objects
Design of frequency-selective surfaces
Develop improved calibration methods
Improve polarimetric measurements

Specialized antennas for diverse applications





Propagation of signals into and inside buildings
Propagation into Bldg. 9972 from external source
Anechoic chamber design for FARM

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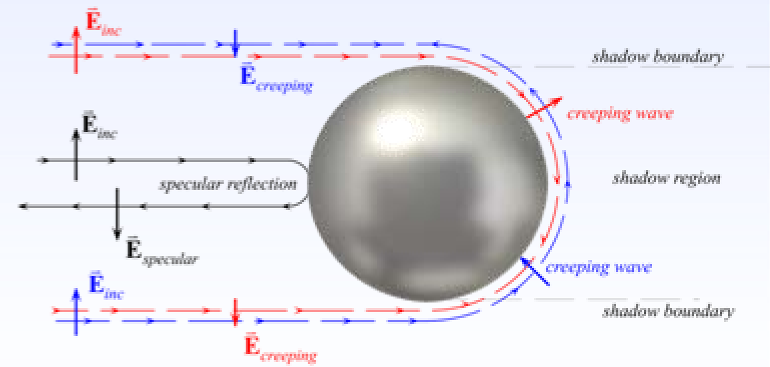
Concepts for Radar Cross Section

What is radar cross section (RCS)?

$$P_{Rx} = \underbrace{\underbrace{P_{Tx}\frac{G_{Tx}}{4\pi r^2}}_{\text{power density at target}} \frac{\sigma}{4\pi r^2}}_{\text{power density at the receiver, from scattering by the target}} \underbrace{\frac{G_{Rx}\lambda^2}{4\pi}}_{\text{effective area of receiving antenna}}$$

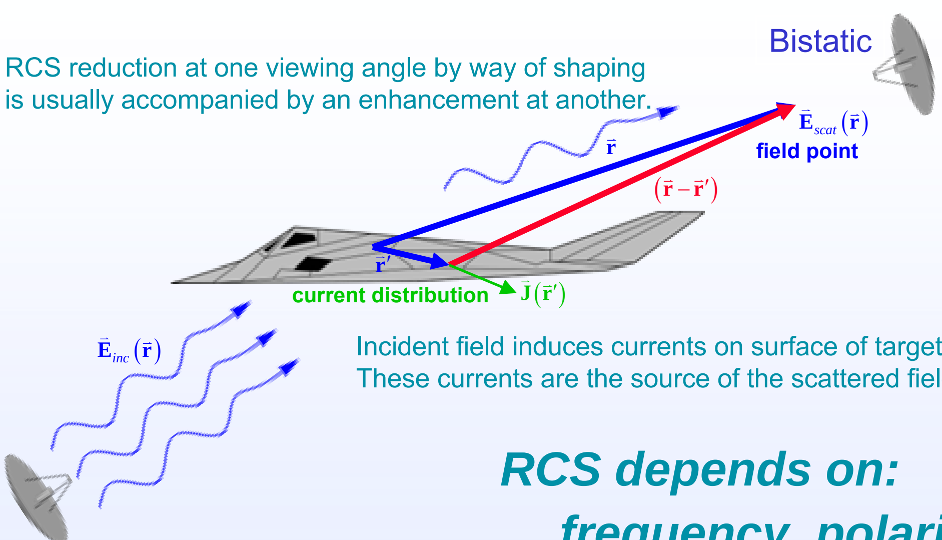
P_{Tx} = transmitted power (watt)
P_{Rx} = received power (watt)
G_{Tx} = transmitter antenna gain
G_{Rx} = receiver antenna gain
r = range to target (m)
σ = radar cross section (m^2)
λ = wavelength of signal (m)



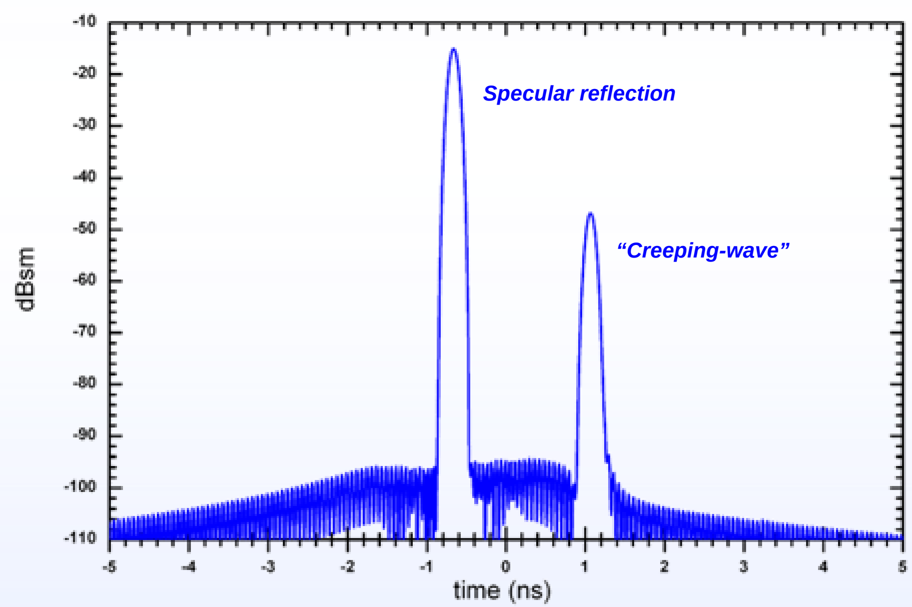
RCS is the projected area of an *isotropic* scatterer that would scatter the same power in a given direction as the *actual* target.

$$\sigma_{tgt} = \lim_{r\to\infty} 4\pi r^2 \frac{\vec{\mathbf{E}}_{scat}(\vec{\mathbf{r}})\cdot\vec{\mathbf{E}}^*_{scat}(\vec{\mathbf{r}})}{\vec{\mathbf{E}}_{inc}\cdot\vec{\mathbf{E}}^*_{inc}} = \vec{\gamma}(\theta,\phi)\cdot\vec{\gamma}^*(\theta,\phi)$$

RCS reduction at one viewing angle by way of shaping is usually accompanied by an enhancement at another.



Incident field induces currents on surface of target
These currents are the source of the scattered field



RCS depends on:

frequency, polarization, material, size, shape, orientation & observation angle!

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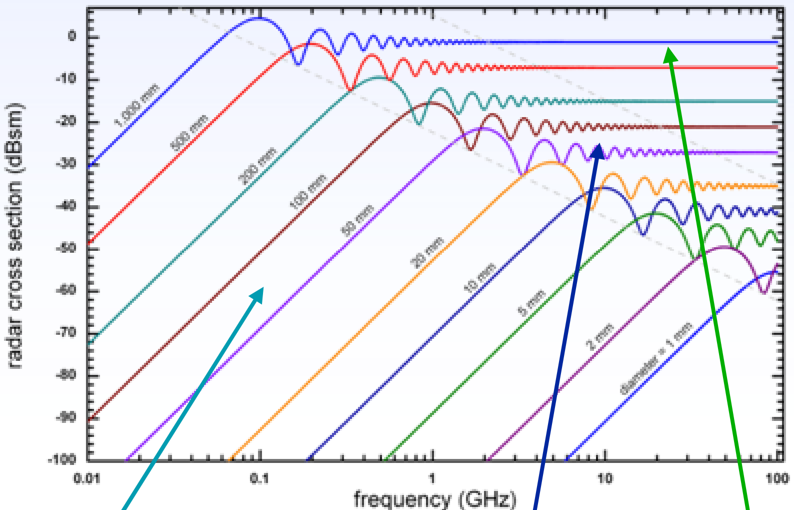
Concepts for Radar Cross Section

RCS vs. frequency for various diameter spheres

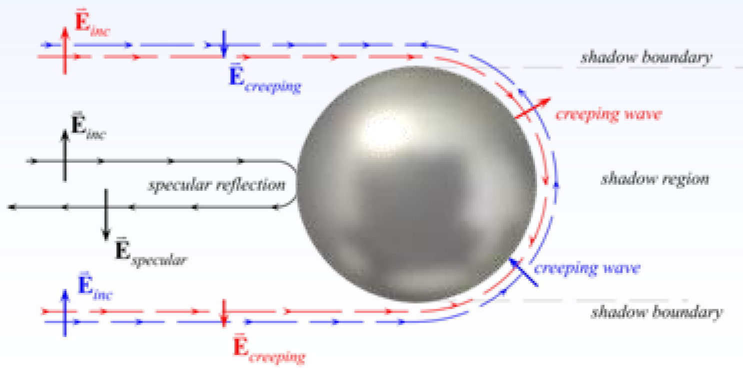


Optical region, $\sigma = \pi d^2/4$

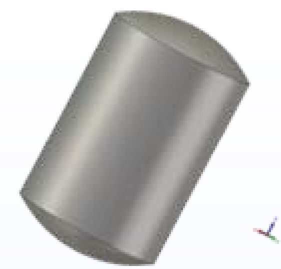
Rayleigh region, $\sigma \sim f^4$ (independent of shape)

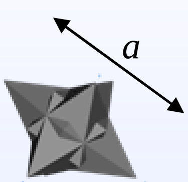
Resonance region, characterized by interference between specular and creeping wave.

RCS of *doubly* curved objects is approximately <u>*constant*</u> with frequency.



RCS of singly curved objects is approximately <u>linear</u> with frequency.





In the Rayleigh region, the object dimensions are measured in fractions of wavelengths ($a < \lambda$), and the RCS increases as the <u>*fourth power*</u> of frequency.

RCS of *flat* objects is approximately <u>*quadratic*</u> with frequency.

RCS depends on:

frequency, polarization, material, size, shape, orientation & observation angle!

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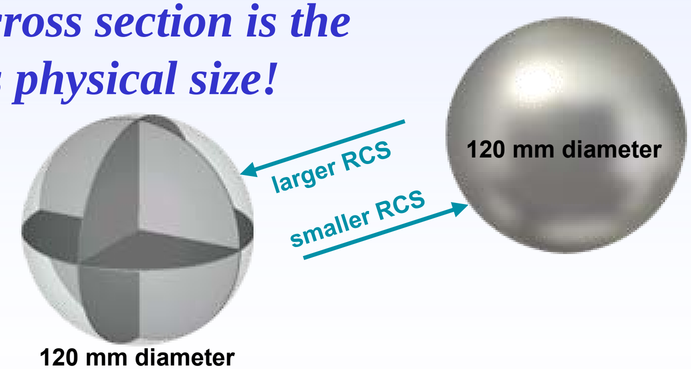
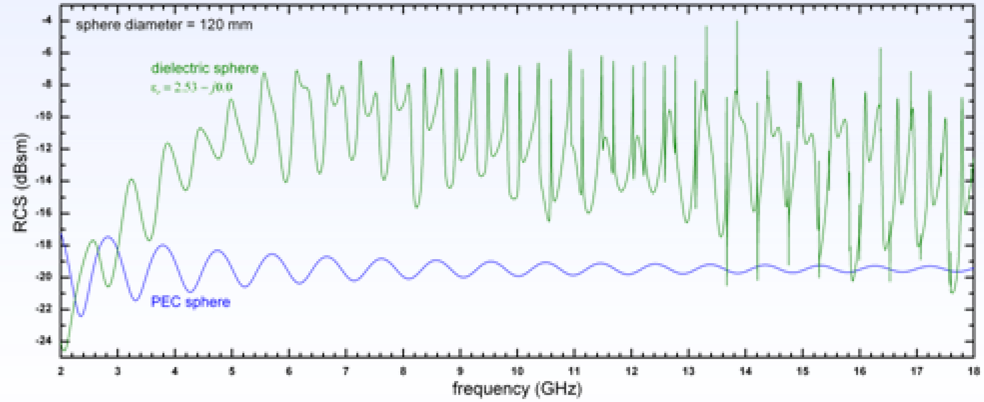
Some Myths About Radar Cross Section

If it's not metal, the radar won't see it!

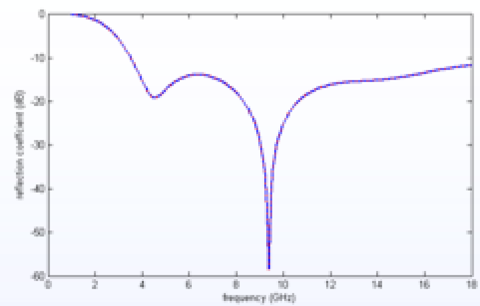
Radar cross section is the same as physical size!



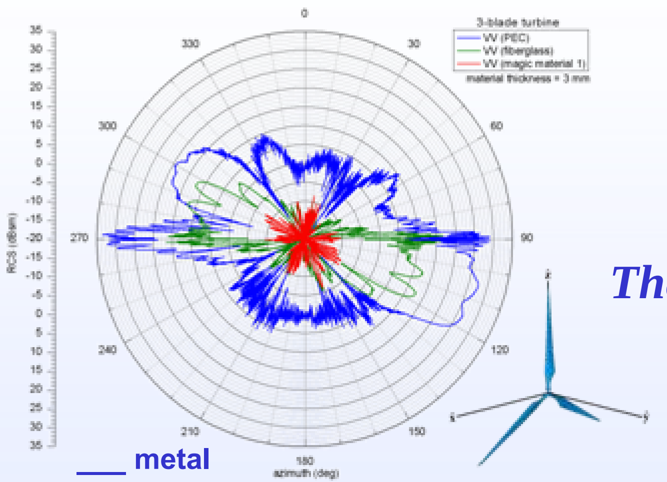


Just buy some "absorbing" paint; that will fix it!

A simple fix works for all frequencies!

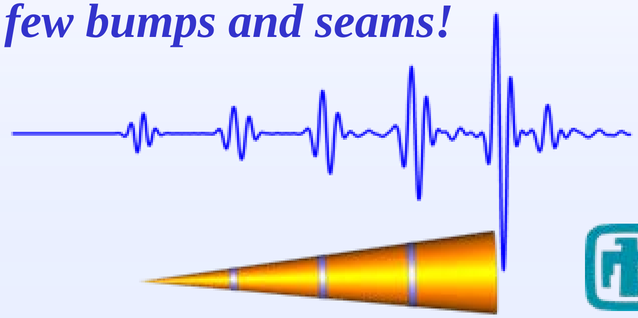


How about a cloaking device!



___ metal
___ fiberglass
___ Weston's magic material; $\varepsilon_r = \mu_r$
(this material doesn't exist, yet)

The radar won't see a few bumps and seams!



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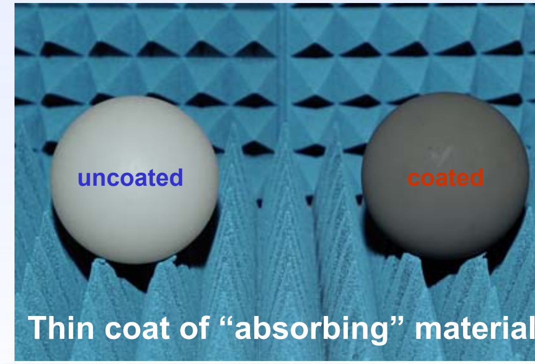
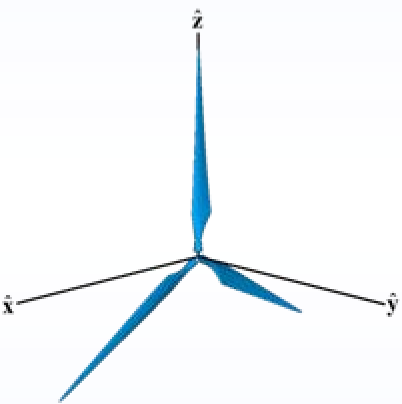
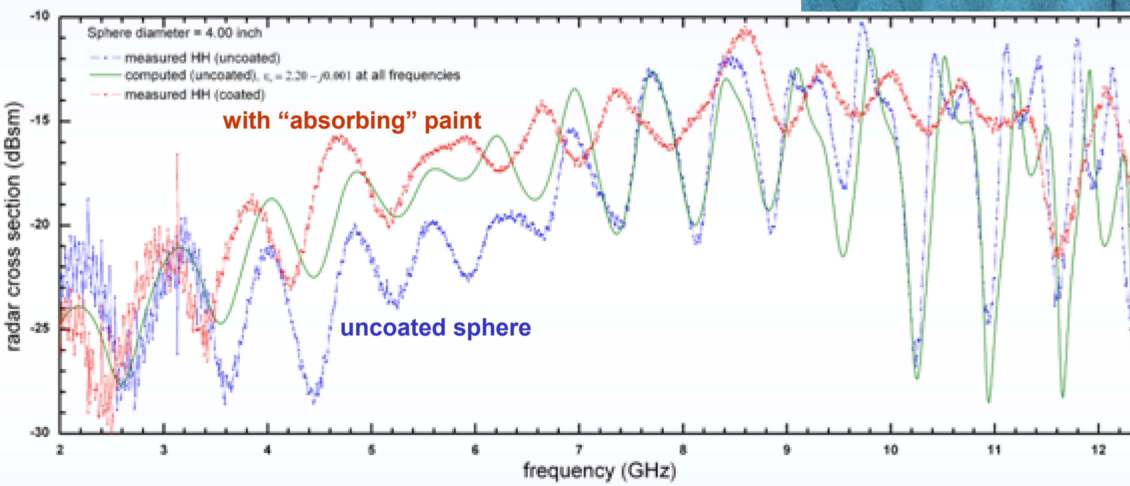
Considerations for Low Radar Cross Section



What will Not Work for Wind Technologies

- Modification of blade geometry
- Ferrite/iron-loaded elastomer–based sheet material applied by bonding
- Thin coat of “absorbing” material applied like a paint





Useful technologies

- Tailoring microwave properties of laminates integrated into lay-up (with or without metal backing)
- Thin, engineered materials
  - Frequency-selective absorber
  - Metamaterial structures (two- and three-dimensional)
  - Metal-backed or bare dielectric substrates

Challenges

- Maintain the mechanical integrity of the turbine blade
- Minimizing effects of abrasion and weathering at surface
- Maintaining tolerances on dimensions and microwave properties during manufacture
- Providing ultraviolet-exposure protection

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- **Near-field measurement system**
  - Planar, cylindrical, and spherical scanning
  - 15' x 15' planar-scan area
  - 300 MHz – 40 GHz (not currently continuous; could also go higher)
- **Broad-band, high-resolution compact range for direct-illumination antenna measurements and for monostatic radar-cross-section measurements (including low-observables)**
  - RCS measurements from 1 GHz – 40 GHz, currently configured 2 GHz – 18 GHz
  - Designed to accommodate test objects up 12' long, currently configured for objects ~ 6' long
  - Can accommodate RCS objects in excess of 20,000 lbs. (azimuth only)
  - Antenna measurements currently from 2 GHz – 40 GHz (could go lower with suitable modifications)
- **Broad-band, high-isolation measurement chamber for characterization of RF-transmission properties of thin materials**
  - Currently configured for 2 GHz – 18 GHz
  - Material sample sizes for 8" x 8" up to 27" x 15" (latter preferred)
  - Smaller samples can be accommodated, but measurement becomes more difficult and less precise
- **Precision Gaussian-beam measurement system for characterizing millimeter-wave properties of engineered materials**
  - Focused-beam measurement system which accommodates much smaller material samples
  - Designed for 10 GHz – 6 THz, currently configured for 18 GHz – 26 GHz
  - Fully automated calibration, precision positioning capability (5 μm tolerance)
- **Outdoor measurement range with inverted-V diffraction fence and positioner stations at approximately ⅛ and ¼ mile, for longer-wavelength measurements and/or larger objects**
  - Currently instrumented for 400 MHz – 3 GHz
  - Currently configured for ⅛ mile positioner station only

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