



Introduction to Radar Systems

Target Radar Cross Section

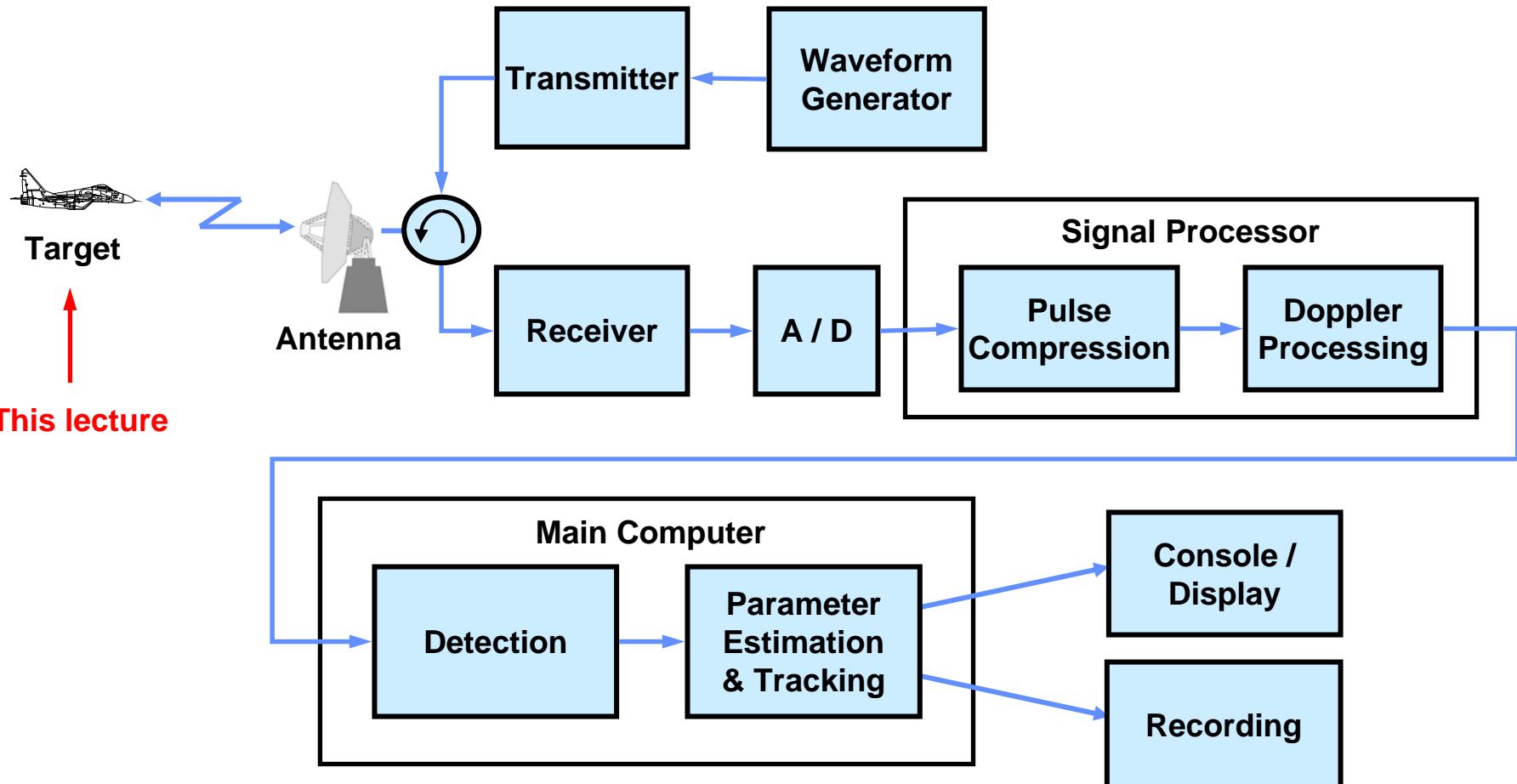


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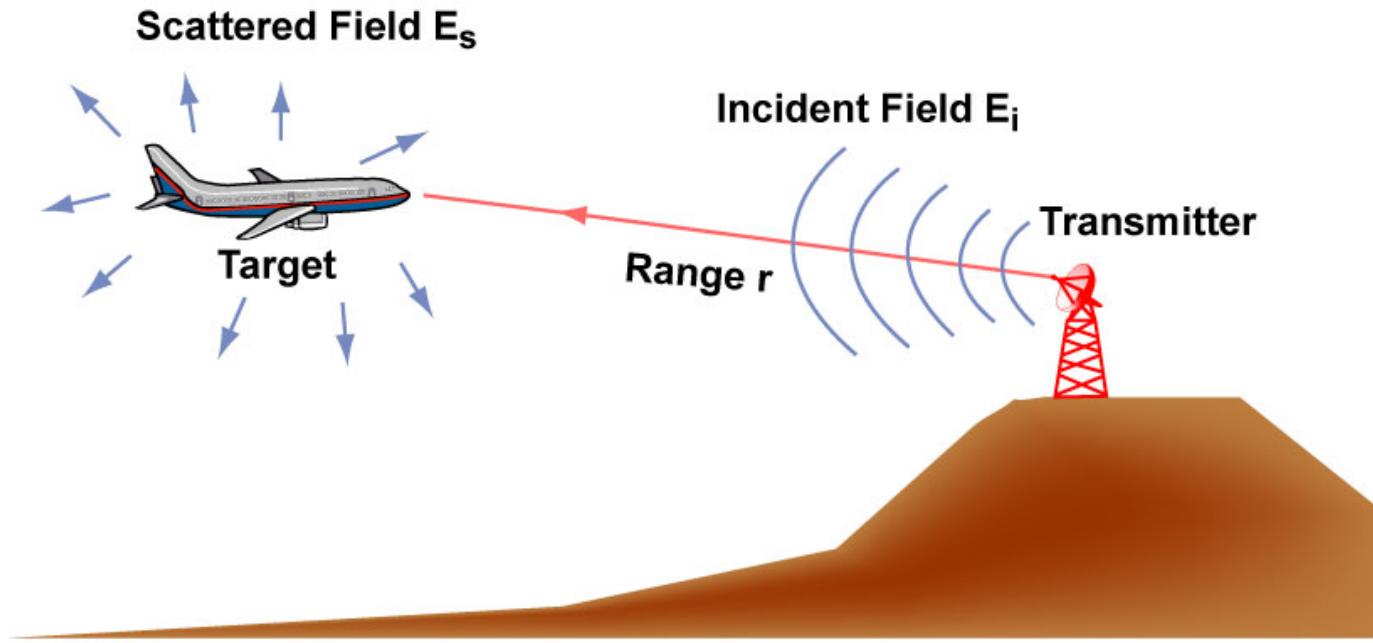


Generic Radar Block Diagram





Definition of Radar Cross Section (RCS or σ)



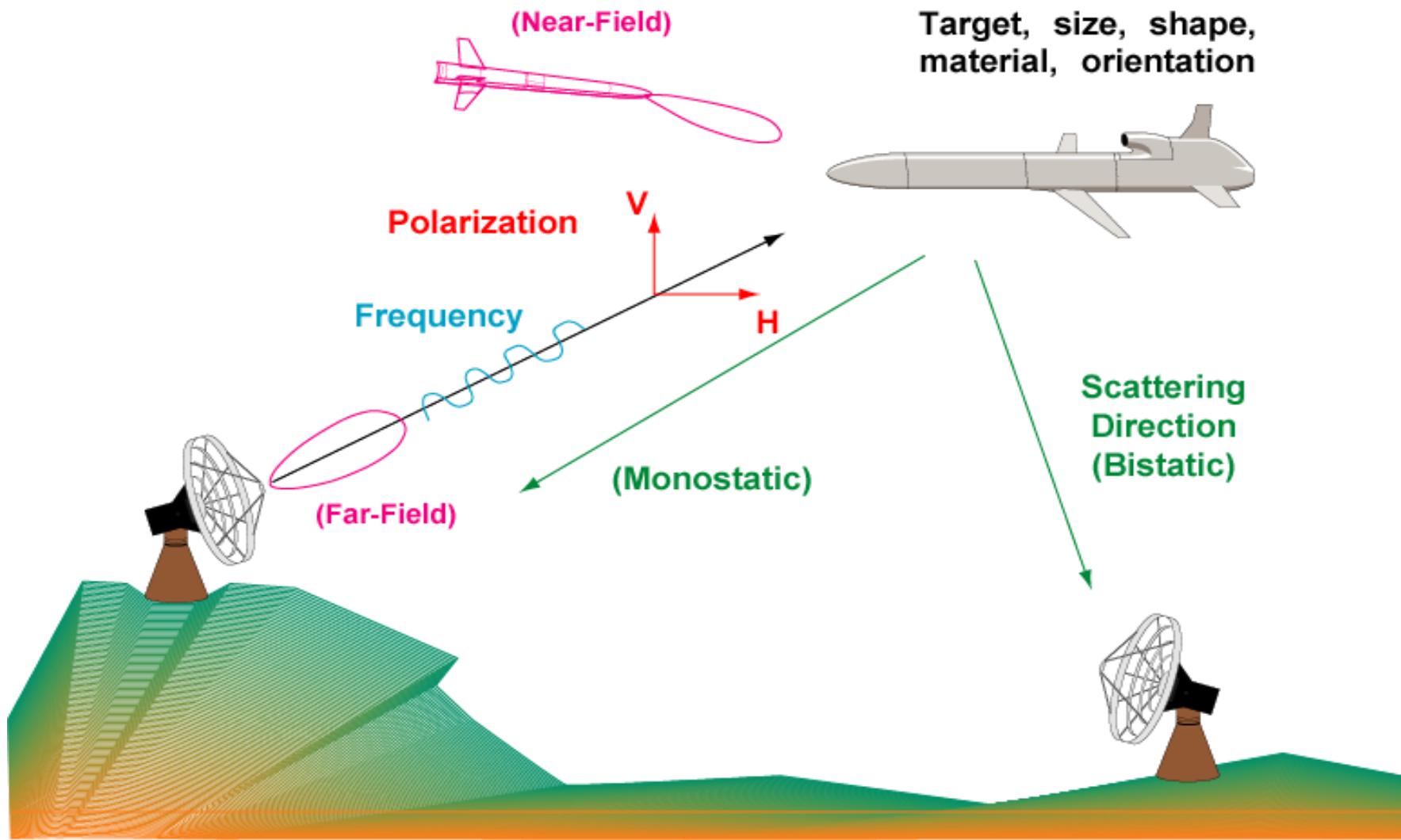
$$\text{RCS} = \lim_{r \rightarrow \infty} 4 \pi r^2 \frac{|E_s|^2}{|E_i|^2} \quad (\text{Unit: Area})$$

Figure by MIT OCW.

Radar Cross Section is the area intercepting that amount of power which, if radiated isotropically, produces the same received power in the radar.



Factors Determining RCS





Threat's View of the Radar Range Equation

What I can control

↓

	Transmit Power	Transmit Gain	Spread Factor	Losses	Target RCS	Spread Factor	Receive Aperture	Dwell Time
--	----------------	---------------	---------------	--------	------------	---------------	------------------	------------

Received Signal Energy = [P_T] $\left[\frac{4\pi A}{\lambda^2} \right]$ $\left[\frac{1}{4\pi R^2} \right]$ $\left[\frac{1}{L} \right]$ [σ] $\left[\frac{1}{4\pi R^2} \right]$ [A] [τ]

The diagram illustrates the radar range equation. At the top, a green arrow points down from the text "What I can control". Below it, a row of parameters is listed: Transmit Power, Transmit Gain, Spread Factor, Losses, Target RCS, Spread Factor, Receive Aperture, and Dwell Time. In the middle, the "Received Signal Energy" equation is shown. The terms [P_T], $\left[\frac{4\pi A}{\lambda^2} \right]$, $\left[\frac{1}{4\pi R^2} \right]$, and [σ] are highlighted in red and have red arrows pointing to the "What I can control" text. The terms $\left[\frac{1}{L} \right]$, [A], and [τ] are also highlighted in red and have red arrows pointing to the text "What I can not control" at the bottom.

What I can not control



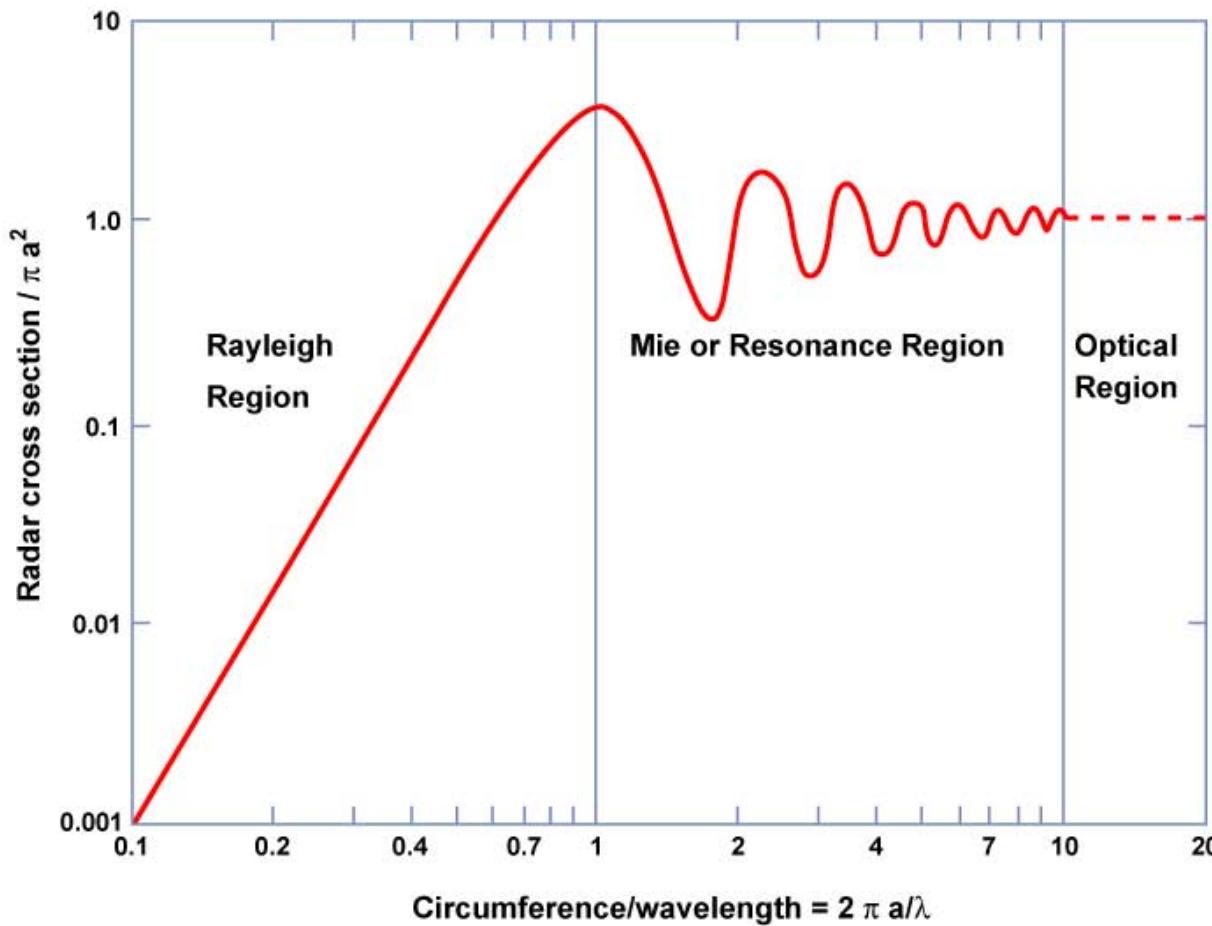
Outline



- **What are typical levels of radar cross section?**
 - On what do these depend?
- **What contributes to radar cross section?**
 - What are the scattering mechanisms?
 - What are typical signature contributors?
- **How can target radar cross section be determined?**
 - Measurement
 - Prediction



Radar Cross Section of Sphere



Rayleigh Region

$$\lambda \gg a$$

$$\sigma = k / \lambda^4$$

Resonance or Mie Region

Oscillations

Backscattered wave interferes with creeping wave

Optical Region

$$\lambda \ll a$$

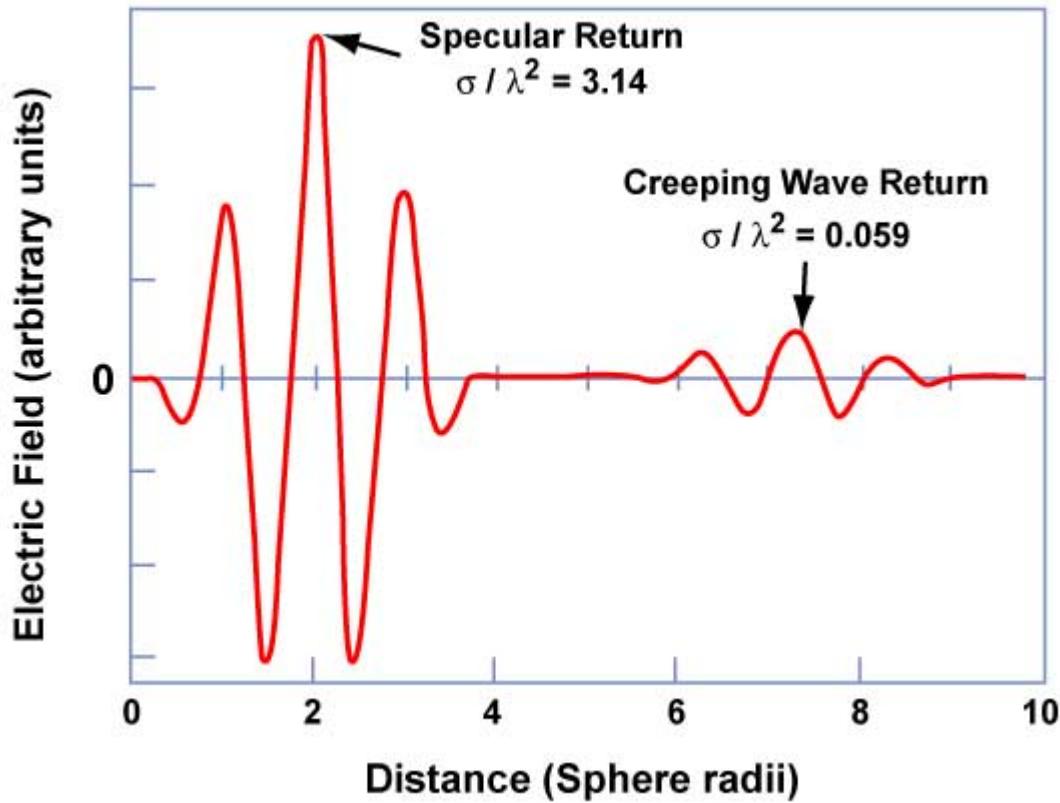
$$\sigma = \pi a^2$$

Surface and edge scattering occur

Figure by MIT OCW.



Backscatter of Short Pulse from Sphere



**Radius of Sphere
is equal to the
radar wavelength**

Figure by MIT OCW.



Radar Cross Section of Typical RV

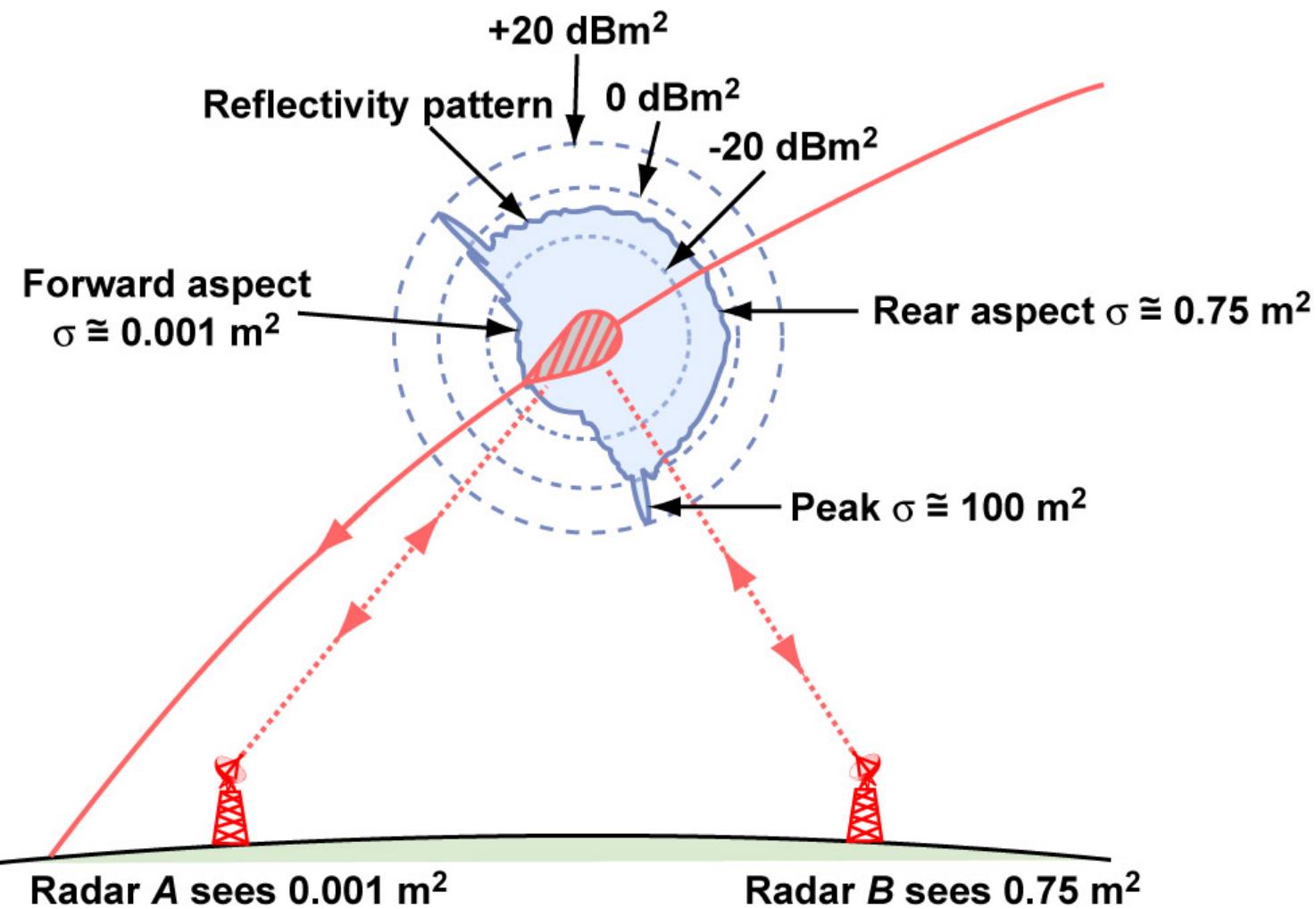


Figure by MIT OCW.



Examples of Radar Cross Sections

	<u>Square meters</u>
Small, single engine aircraft	1
Four passenger jet	2
Large fighter	6
Medium jet airliner	40
Jumbo jet	100
Helicopter	3
Small open boat	0.02
Small pleasure boat (20-30 ft)	2
Cabin cruiser (40-50 ft)	10
Ship(5,000 tons displacement, L Band)	10,000
Automobile / Small truck	100 - 200
Bicycle	2
Man	1
Birds	$10^{-2} - 10^{-3}$
Insects	$10^{-4} - 10^{-5}$

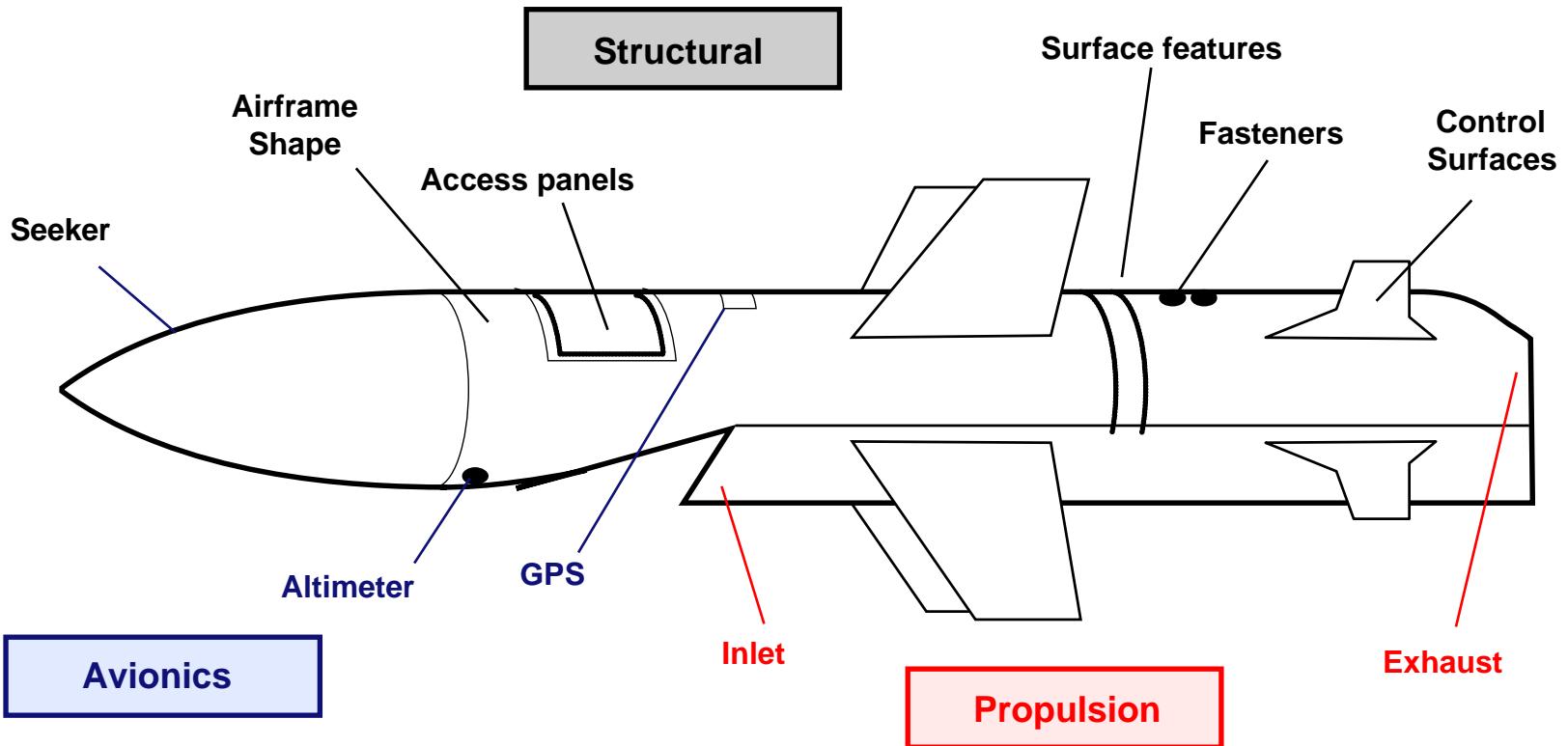


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Components of Target RCS

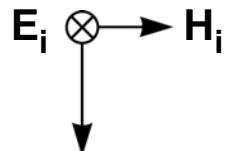


- Three types of RCS contributors:
 - Structural (body shape, control surfaces, etc.)
 - Propulsion (inlets, exhaust, etc.)
 - Avionics (seeker, GPS, altimeter, etc.)

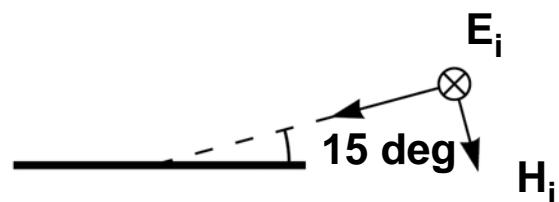


Description of Sample Cases on Video

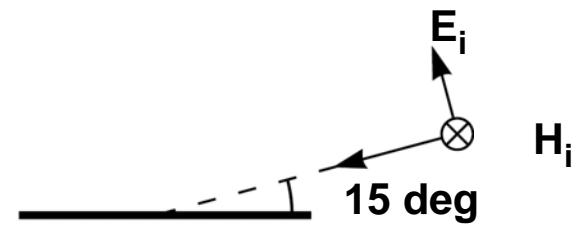
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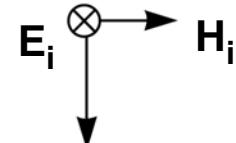
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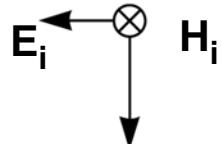
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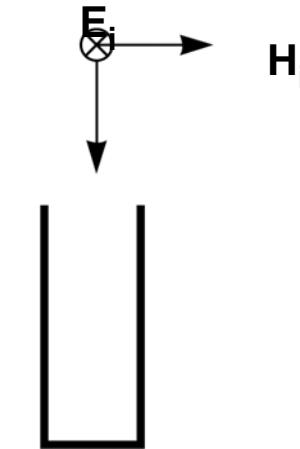
- Case 4



- Case 5



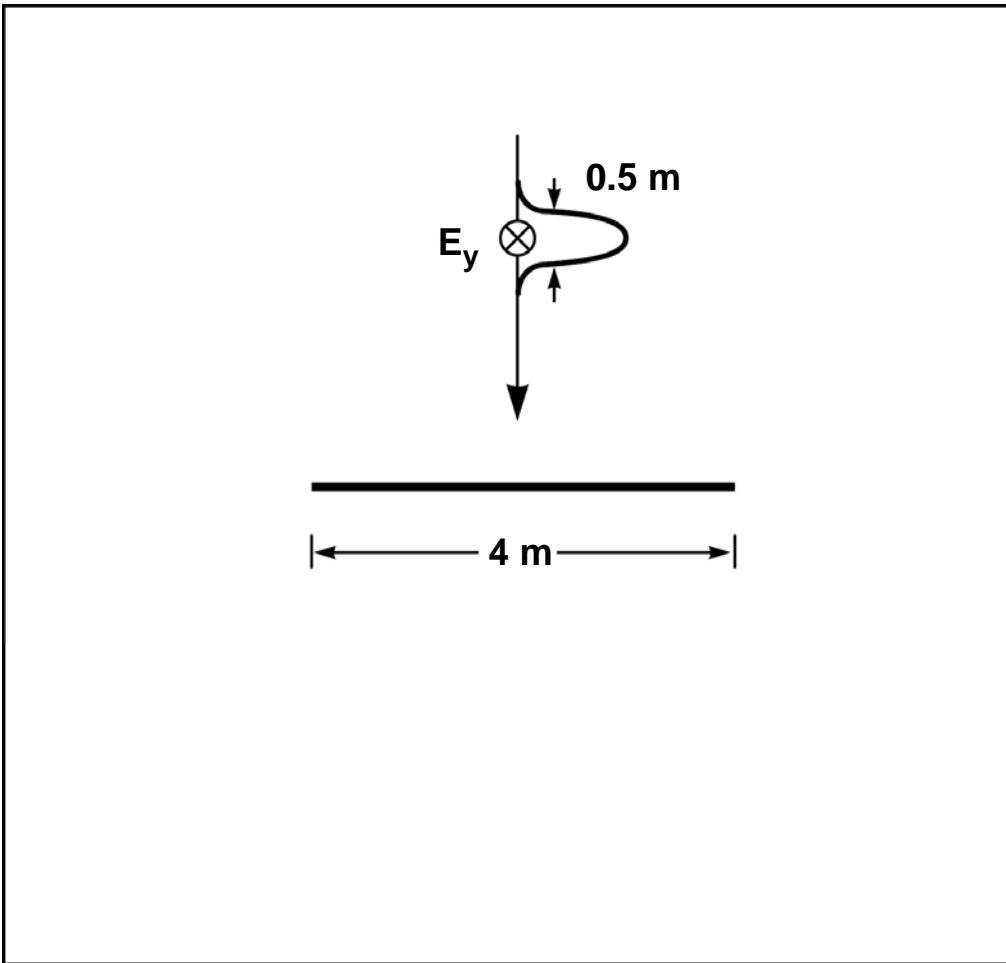
- Case 6

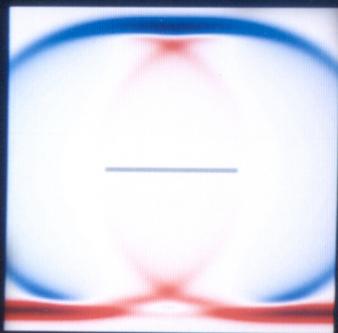
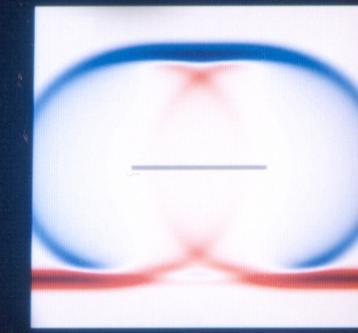
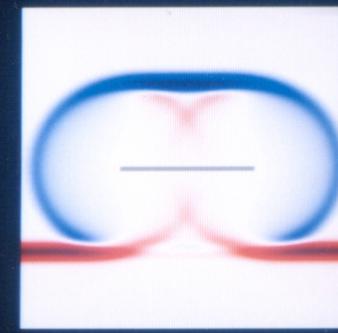
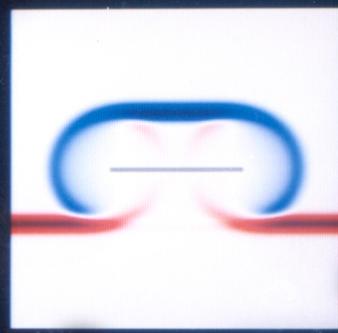
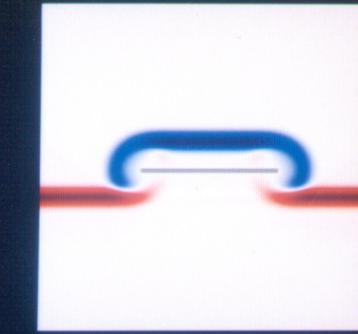
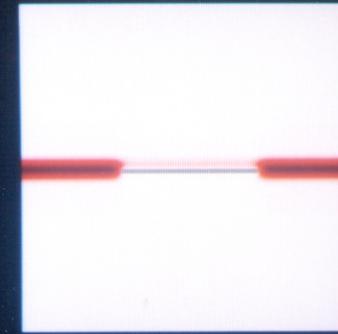




FD-TD Simulation of Scattering by Strip

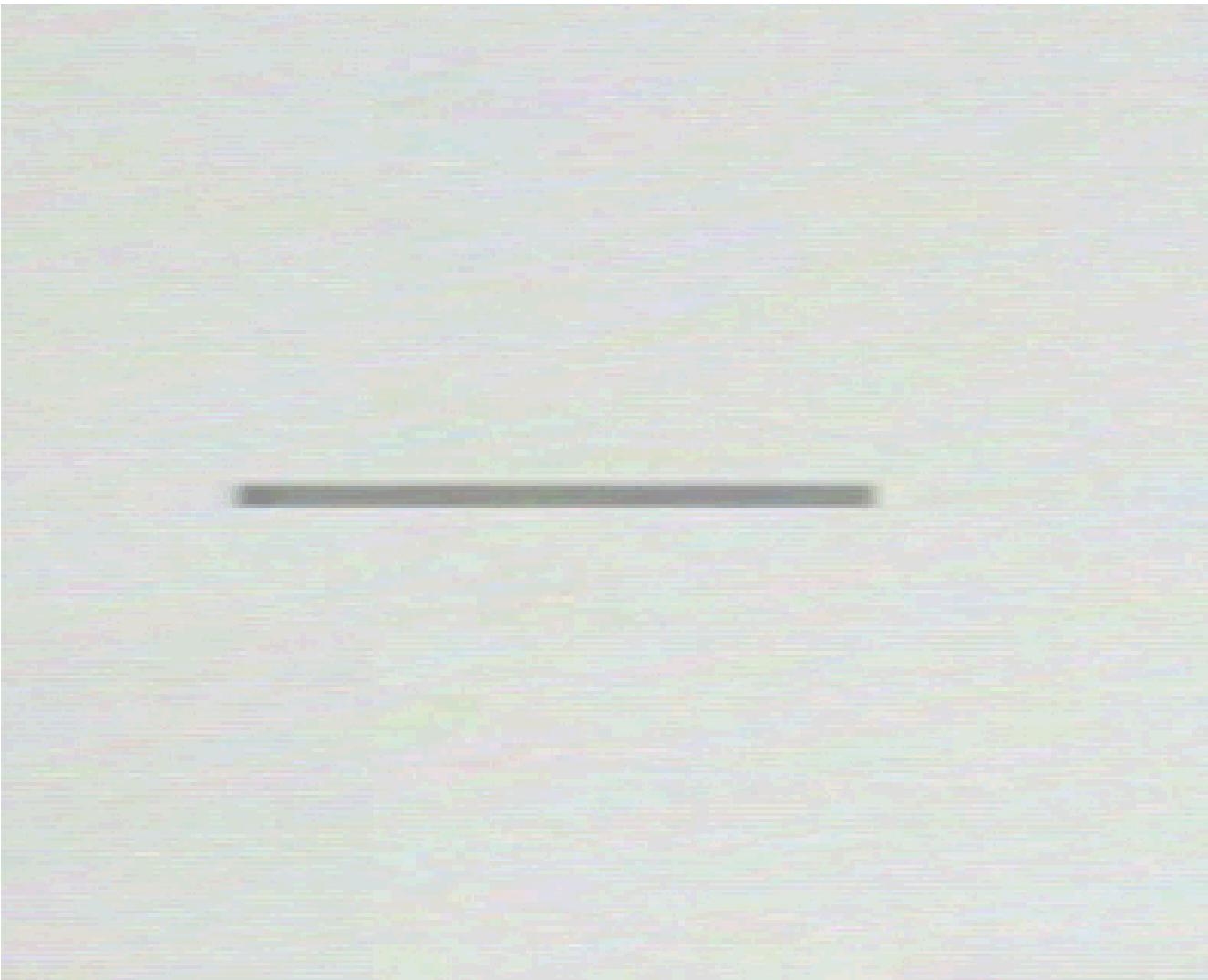
- Gaussian pulse plane wave incidence
- E-field polarization (E_y plotted)
- **Phenomena: specular reflection**







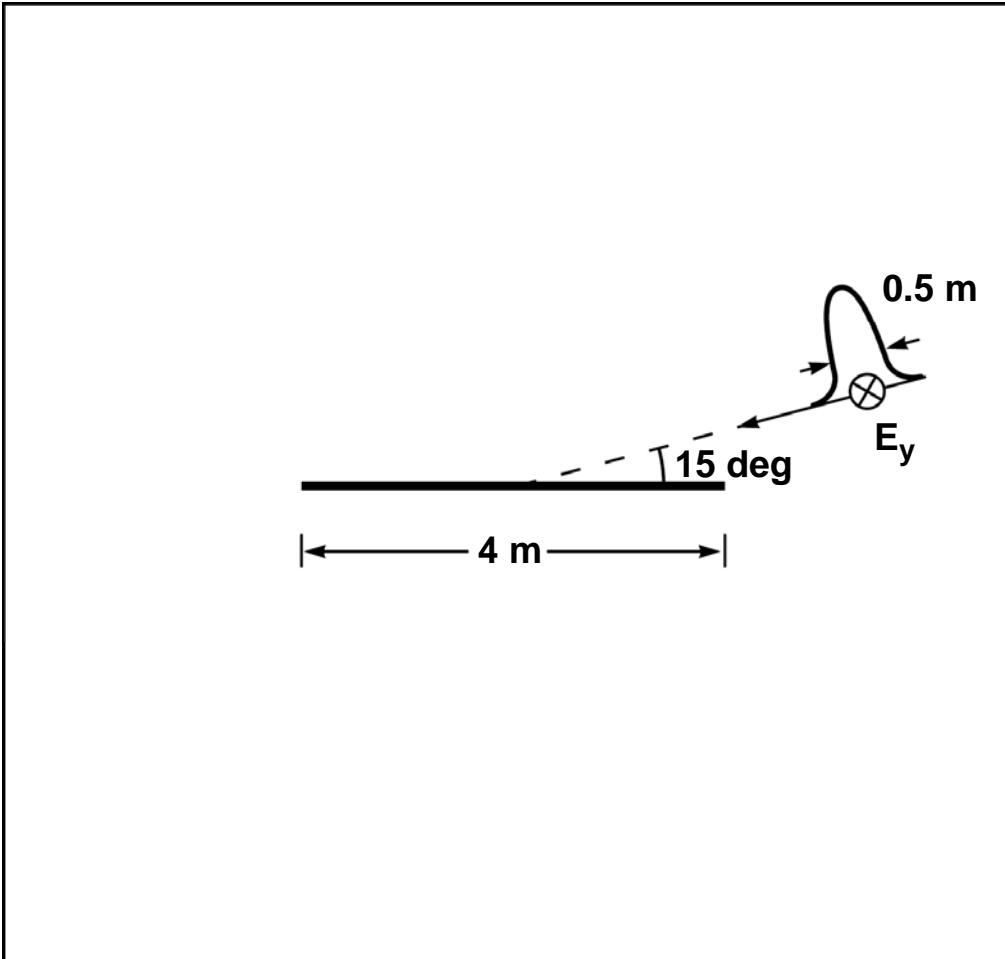
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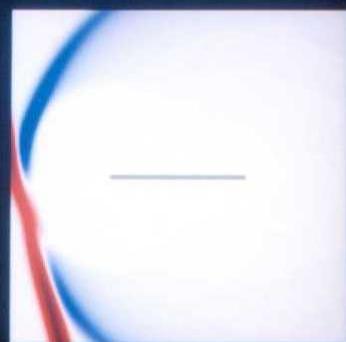
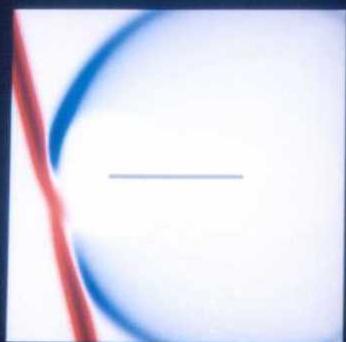
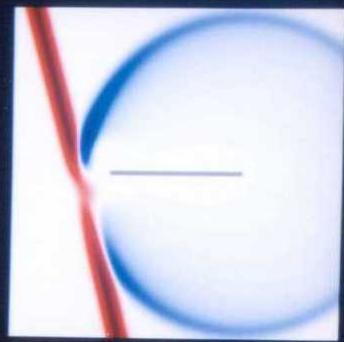
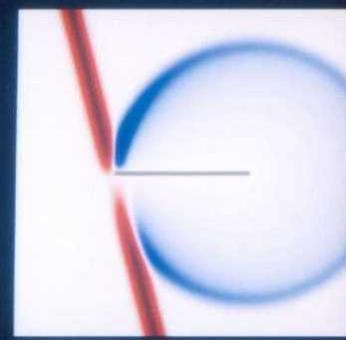
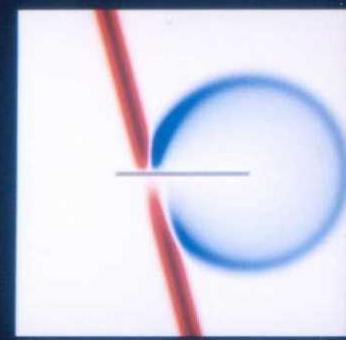
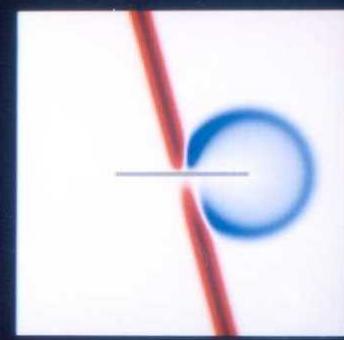
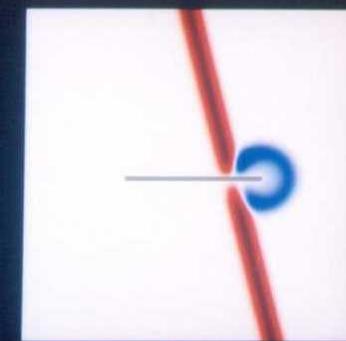
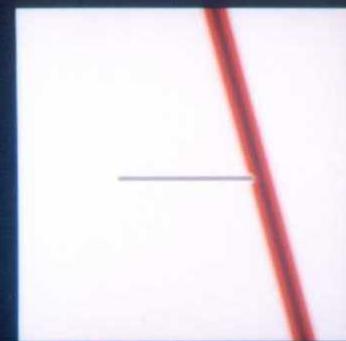
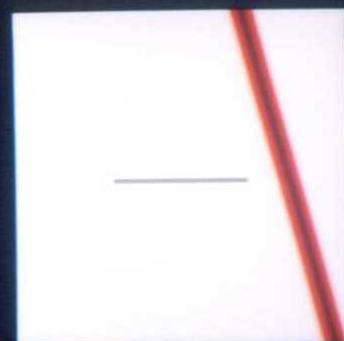




FD-TD Simulation of Scattering by Strip

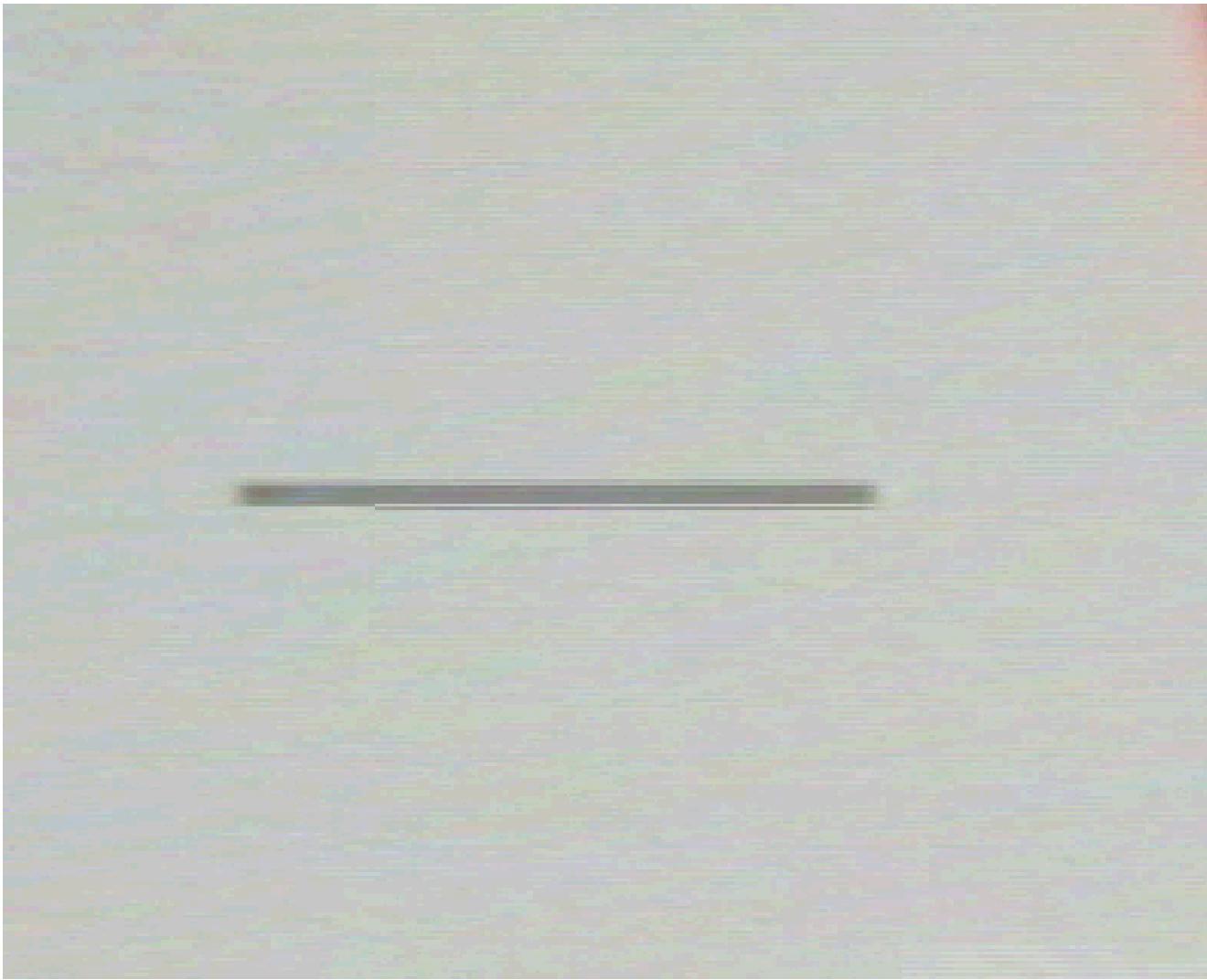
- Gaussian pulse plane wave incidence
- E-field polarization (E_y plotted)
- **Phenomena: leading edge diffraction**







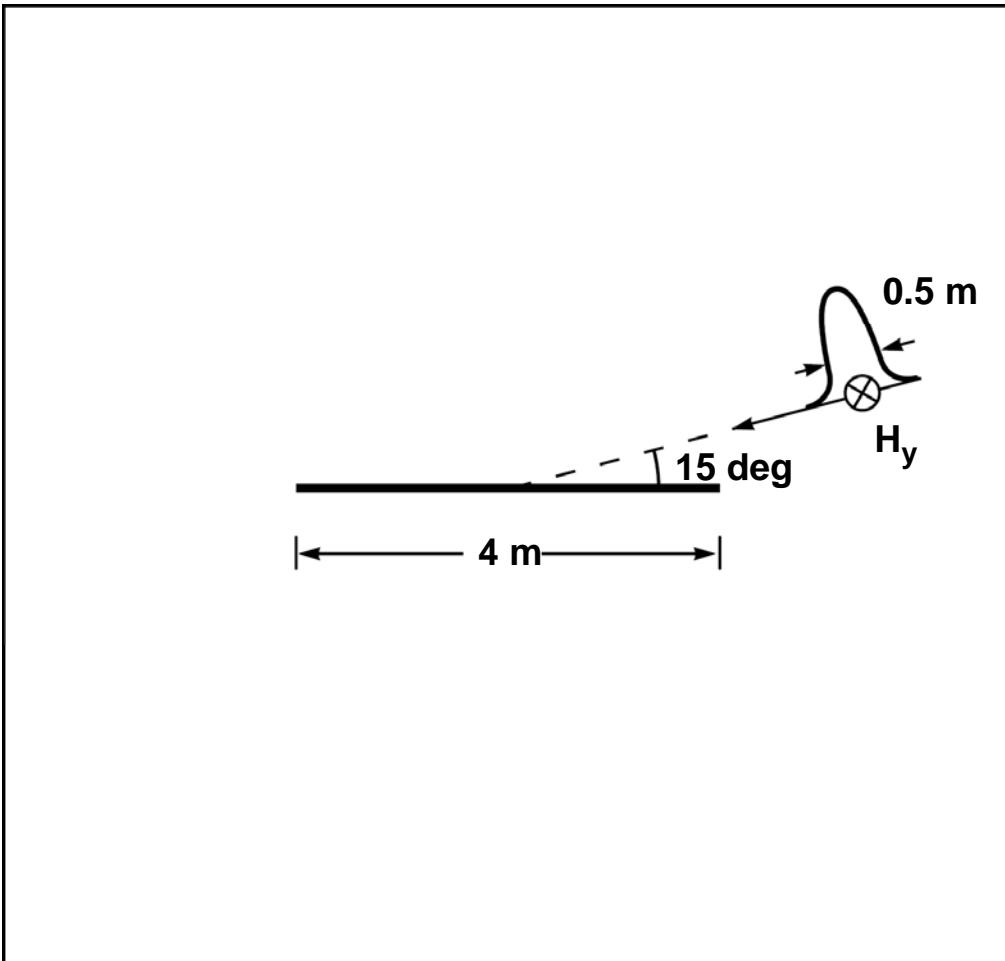
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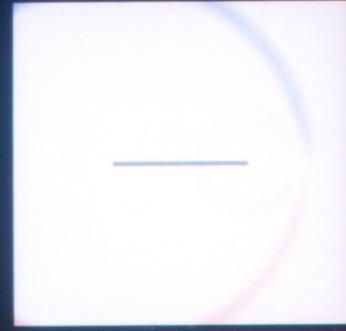
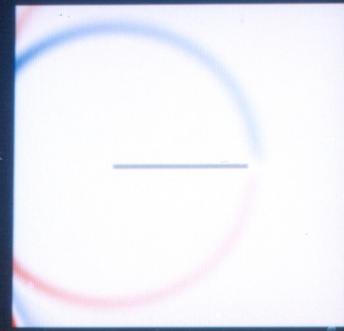
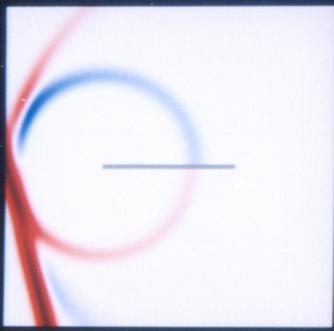
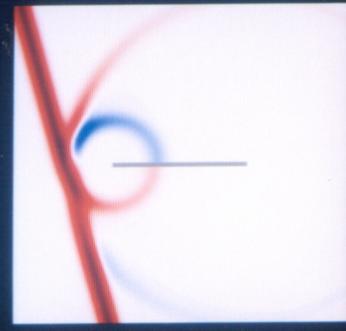
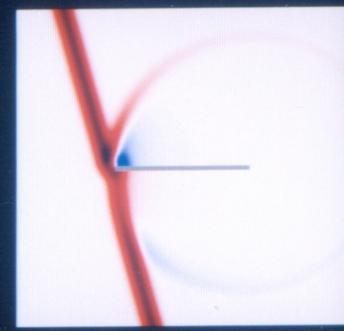
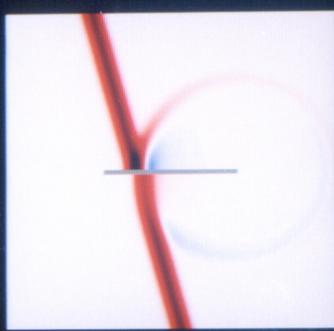
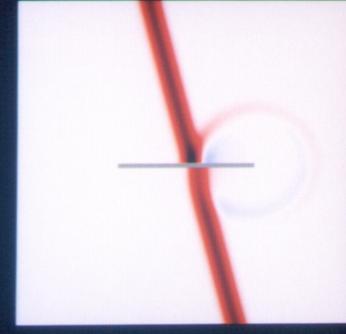
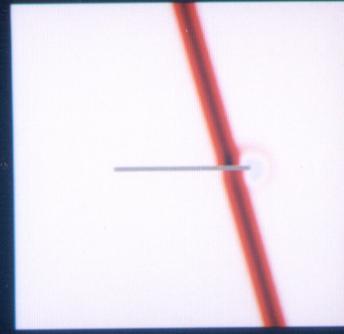
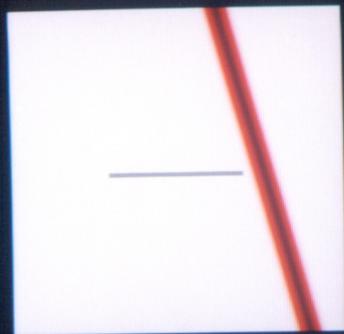




FD-TD Simulation of Scattering by Strip

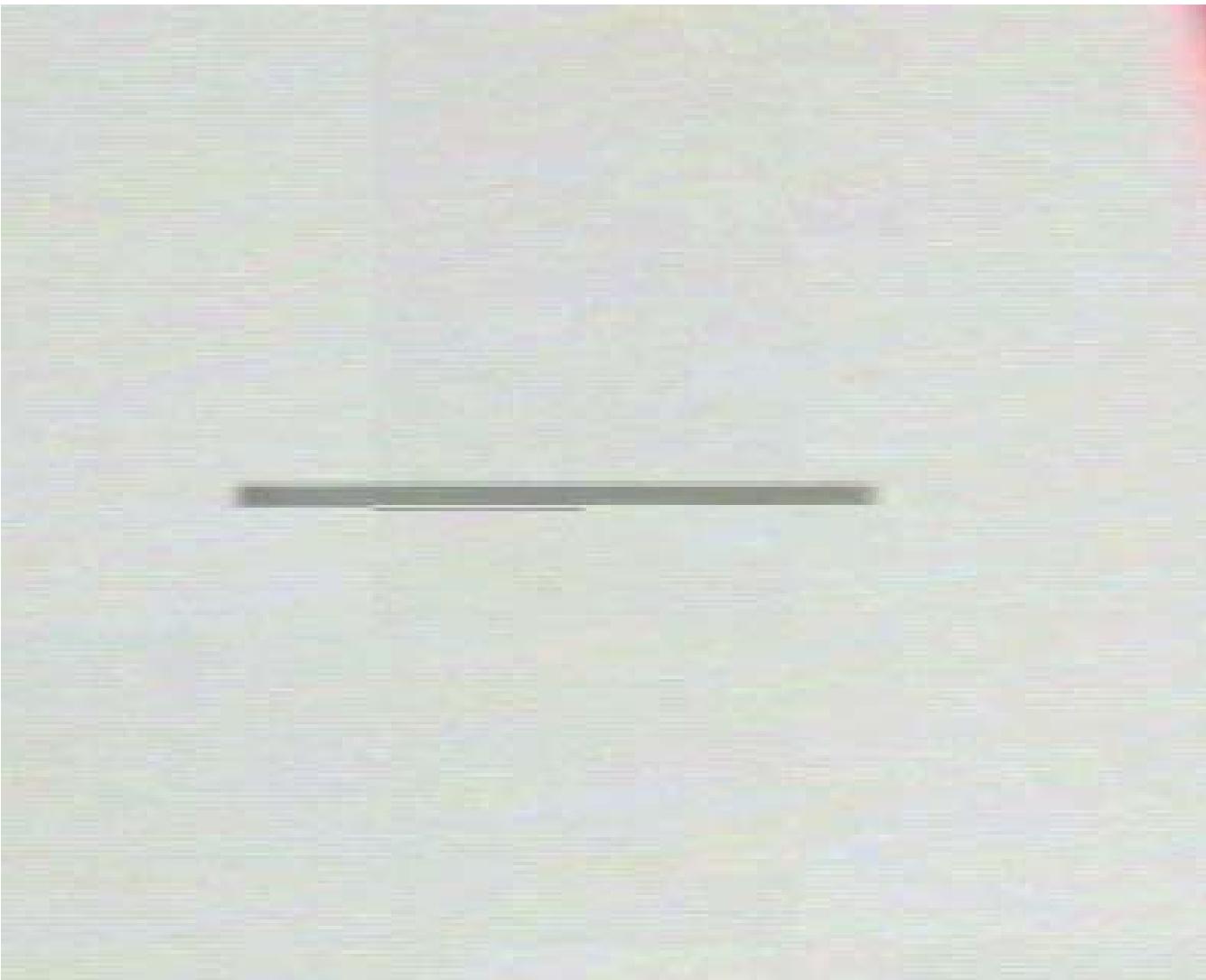
- Gaussian pulse plane wave incidence
- H-field polarization (H_y plotted)
- **Phenomena: trailing edge diffraction**







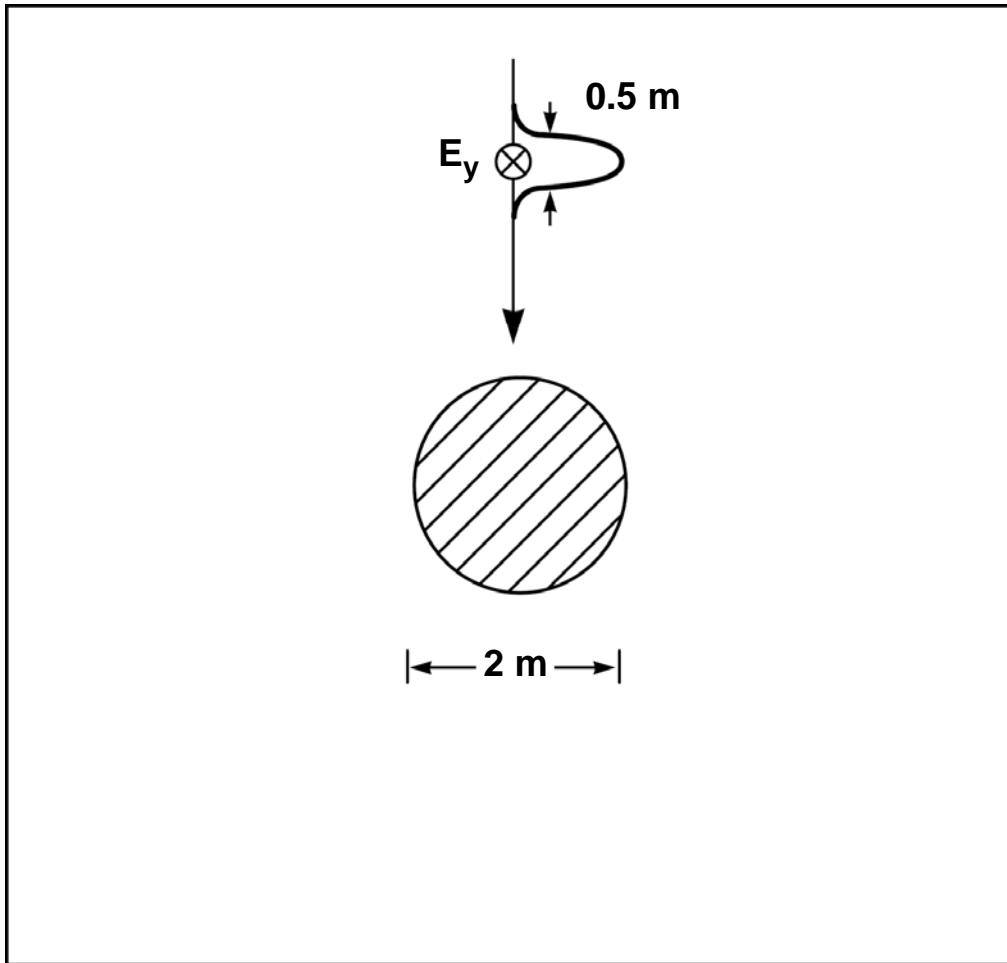
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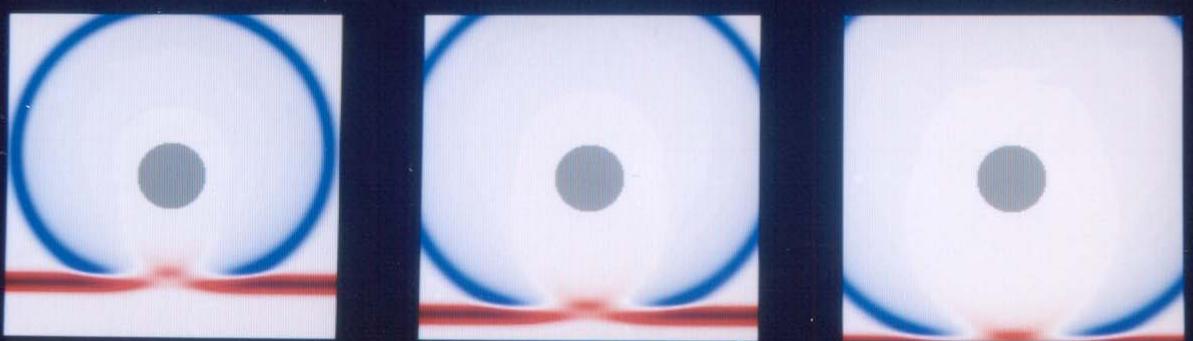
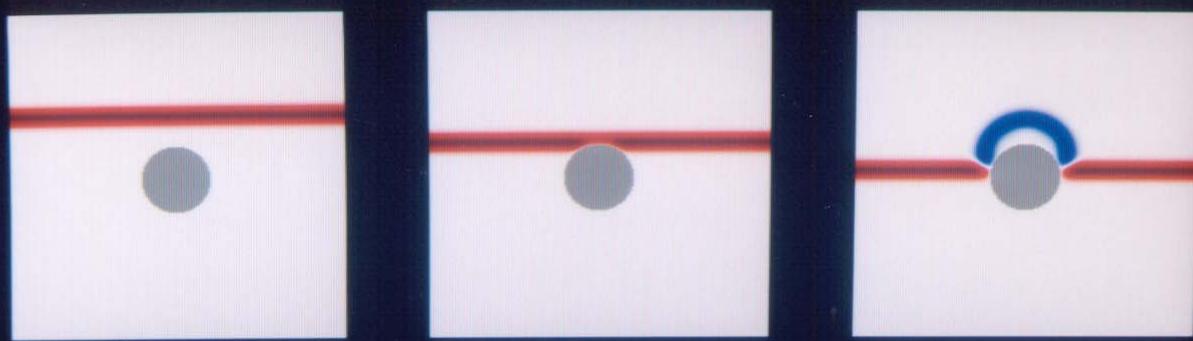




FD-TD Simulation of Scattering by Cylinder

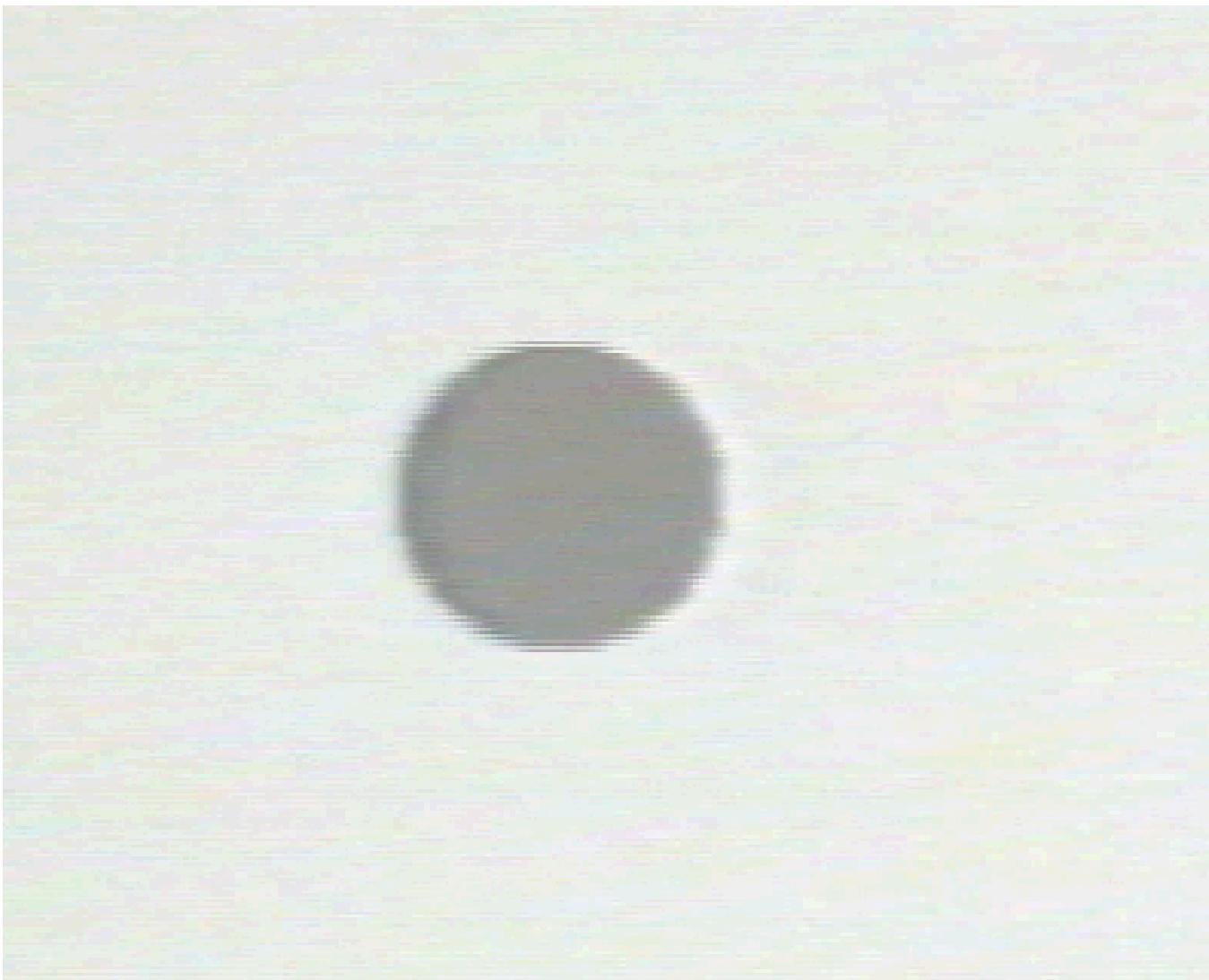
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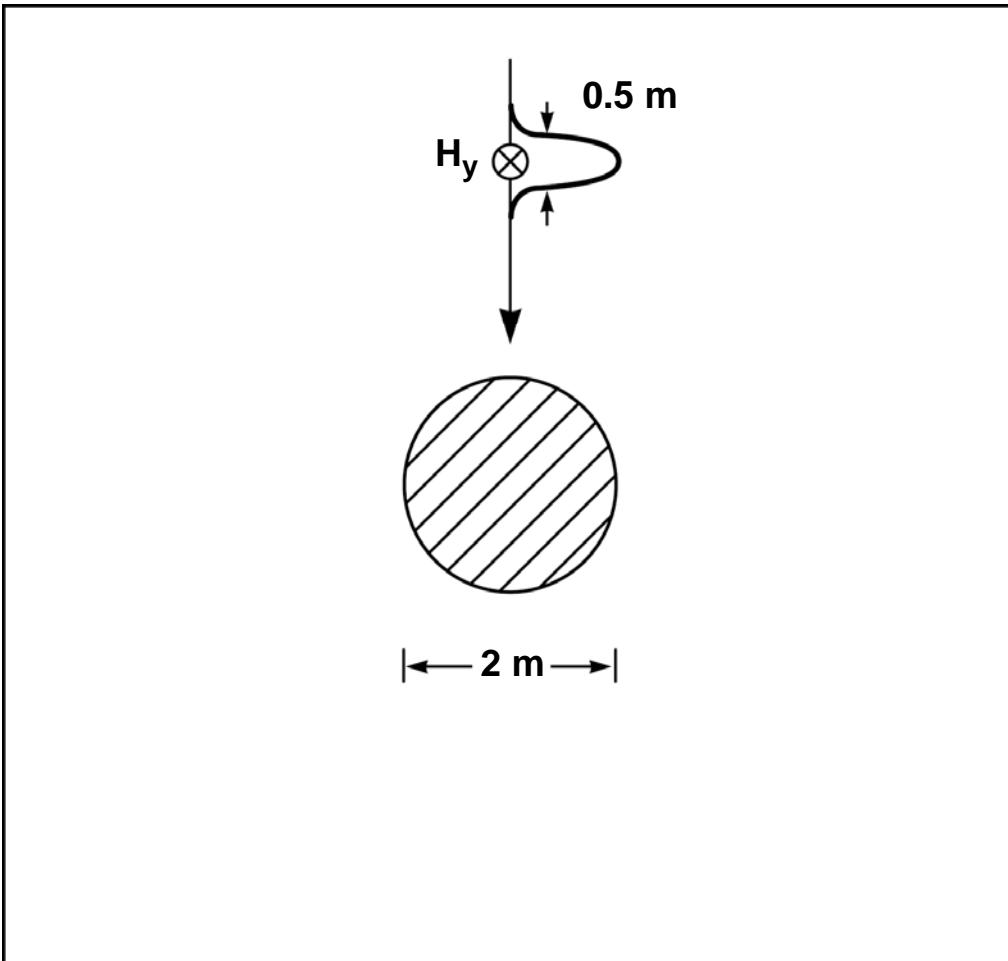
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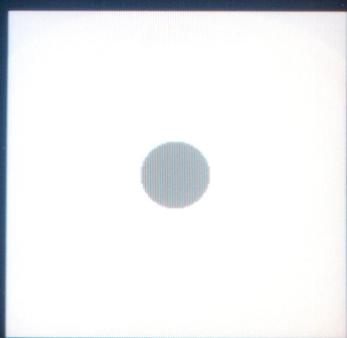
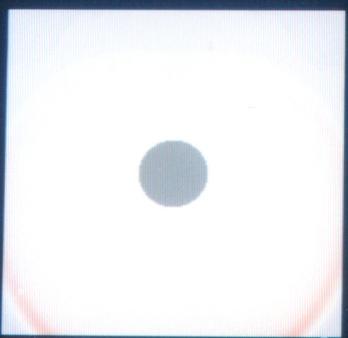
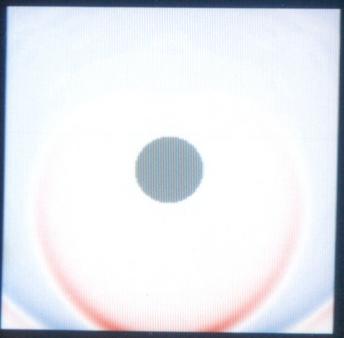
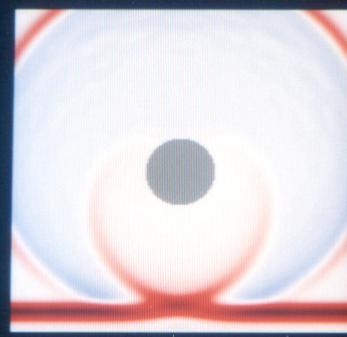
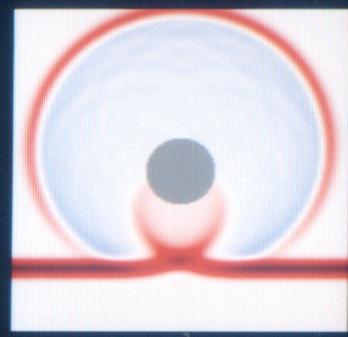
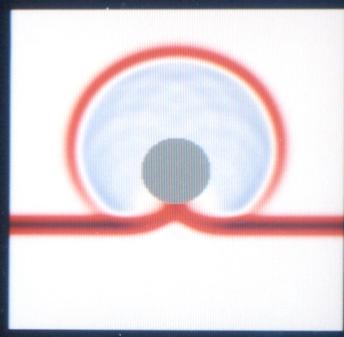
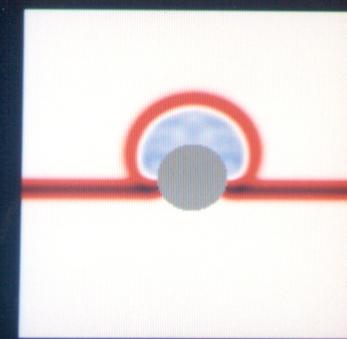
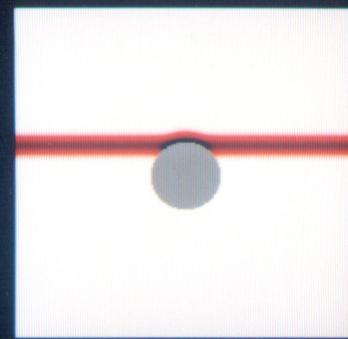
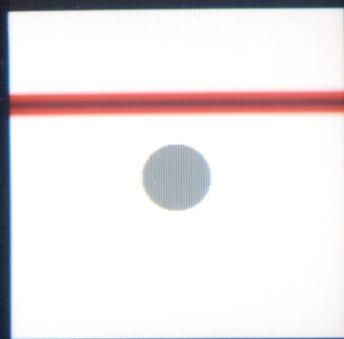




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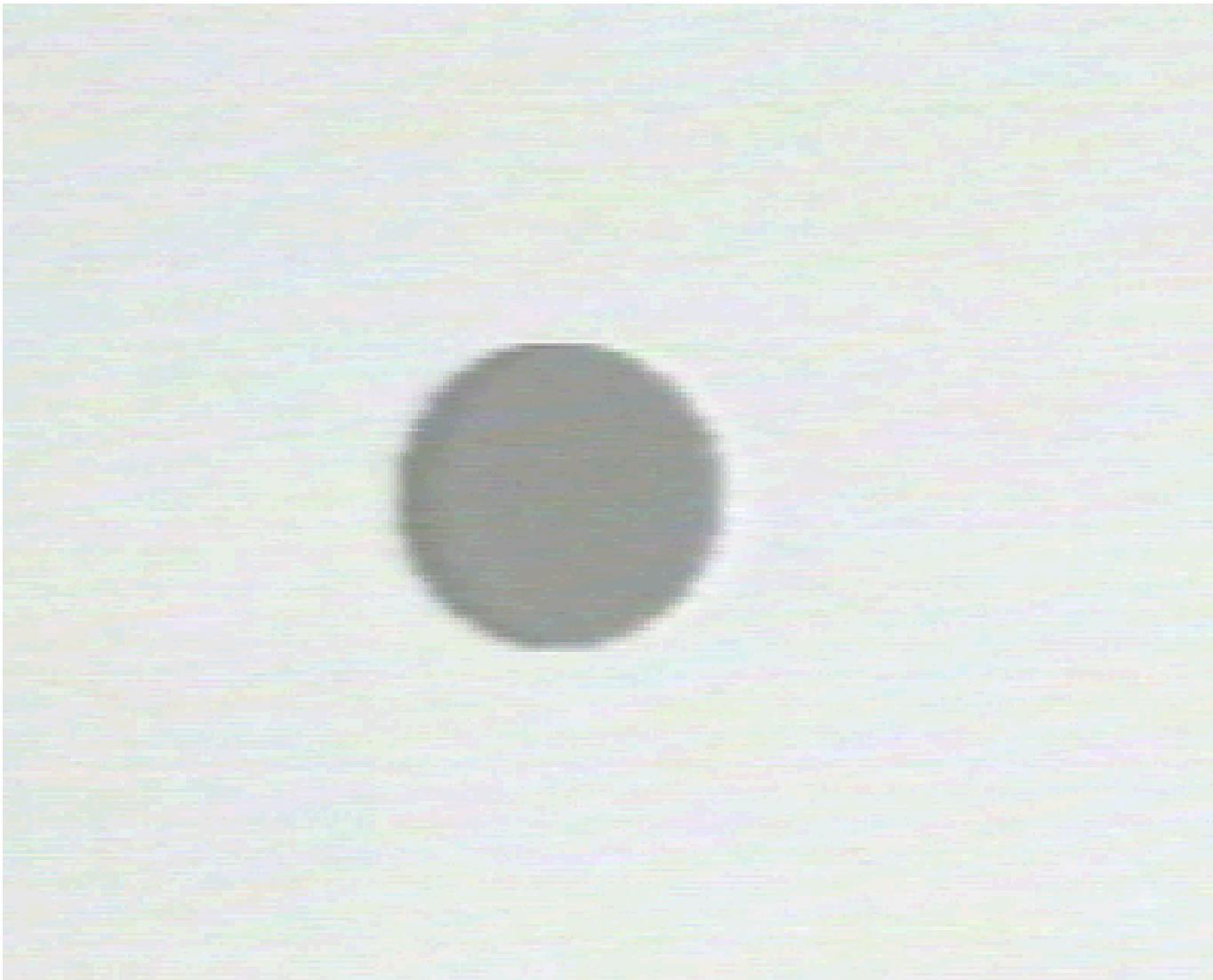
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- **Phenomena: creeping wave**







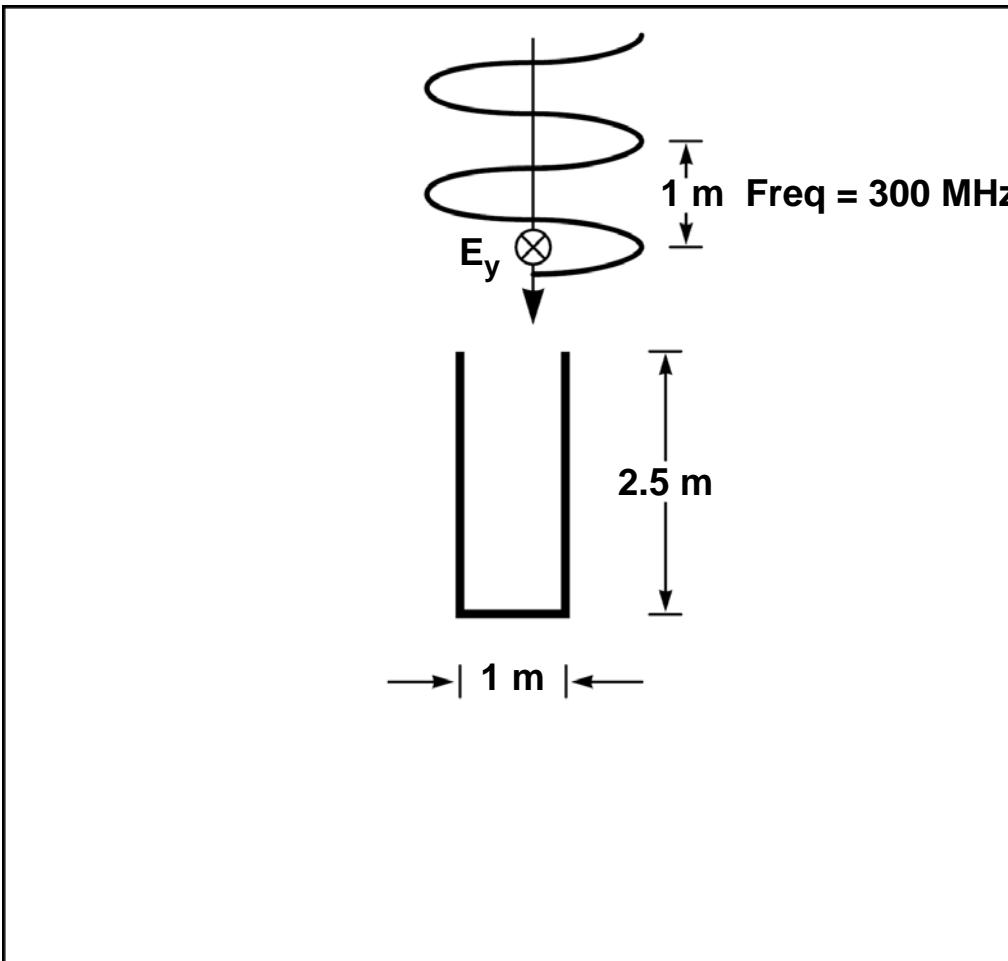
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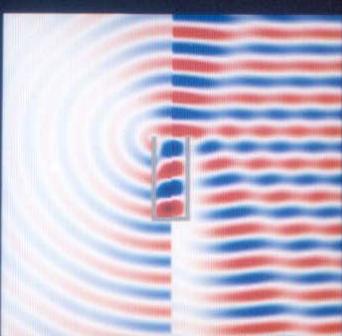
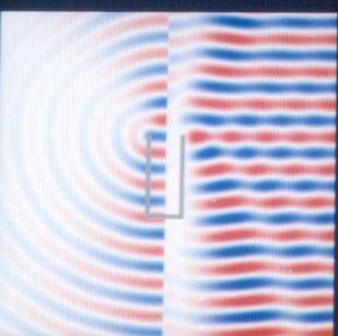
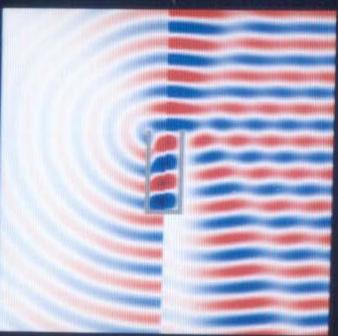
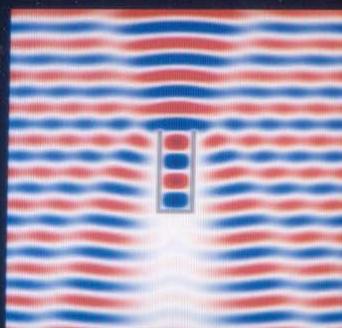
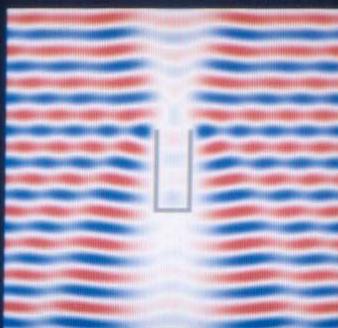
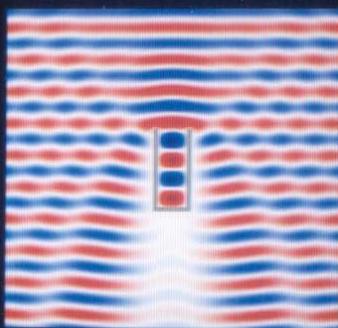
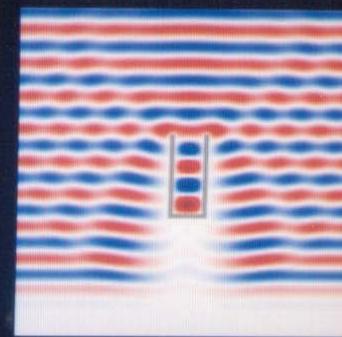
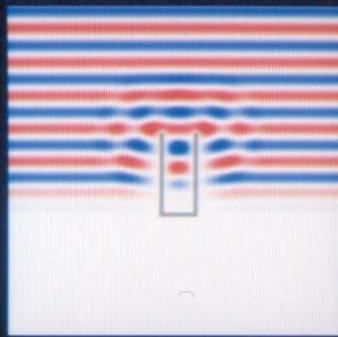
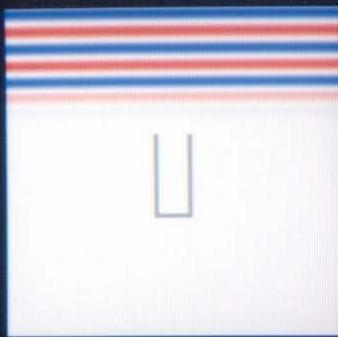




FD-TD Simulation of Scattering by Cavity

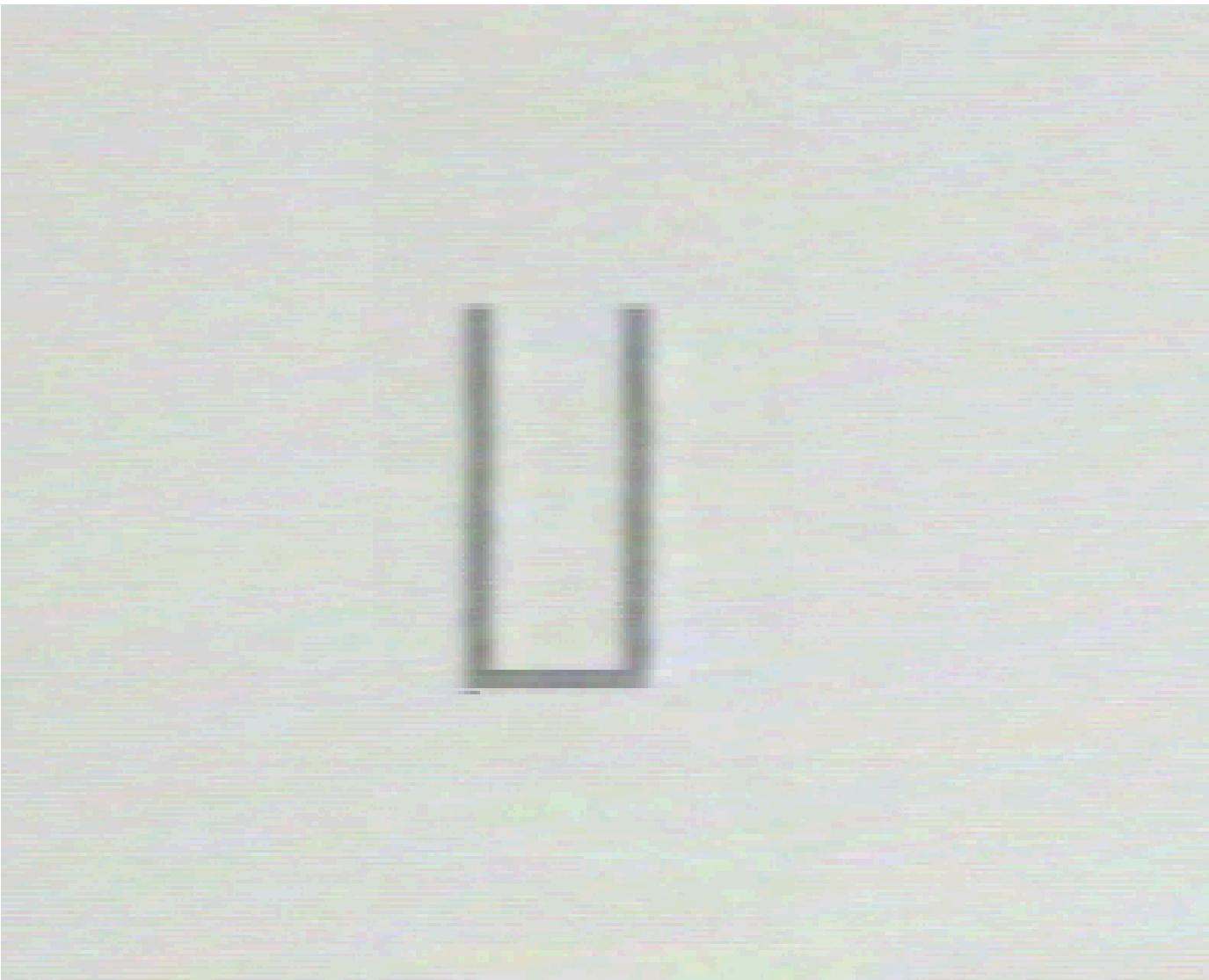
- Sinusoidal plane wave incidence
- E-field polarization (E_y plotted)
- **Phenomena: standing wave**







FD-TD Simulation of Scattering by Cavity





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Techniques for RCS Analysis

FULL SCALE MEASUREMENTS



RCS PREDICTION

SCALED MODEL MEASUREMENTS



Full Scale Measurements

Target on support

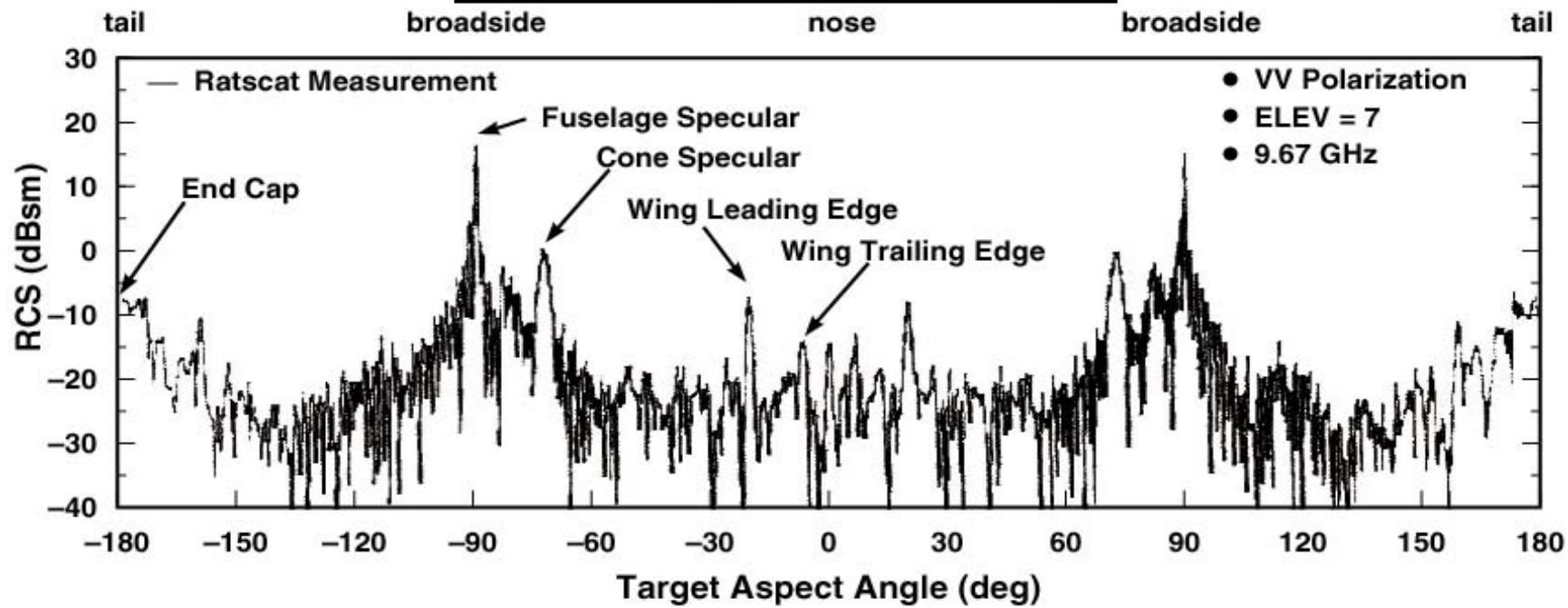
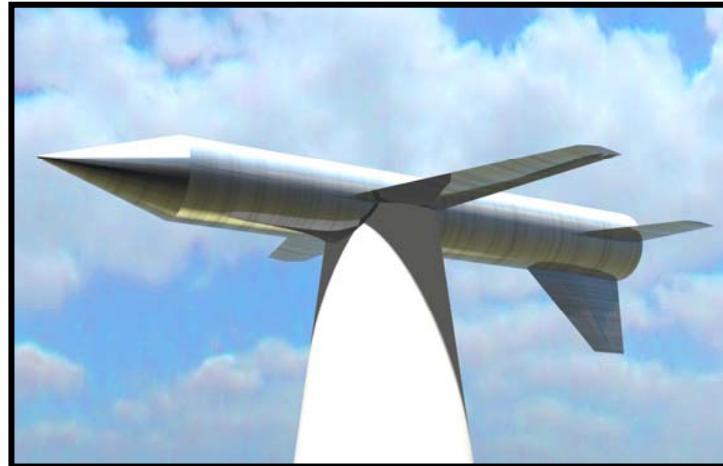


- **Foam column mounting**
 - Dielectric properties of styrofoam close to those of free space
- **Metal pylon mounting**
 - Metal pylon shaped to reduce radar reflections
 - Background subtraction can be used

Derived from: <http://www.af.mil/shared/media/photodb/photos/050805-F-0000S-003.jpg>



Johnson Generic Aircraft Model (JGAM)





Compact Range RCS Measurement

• Radar Reflectivity Laboratory (Pt. Mugu) / AFRL Compact Range (WPAFB)

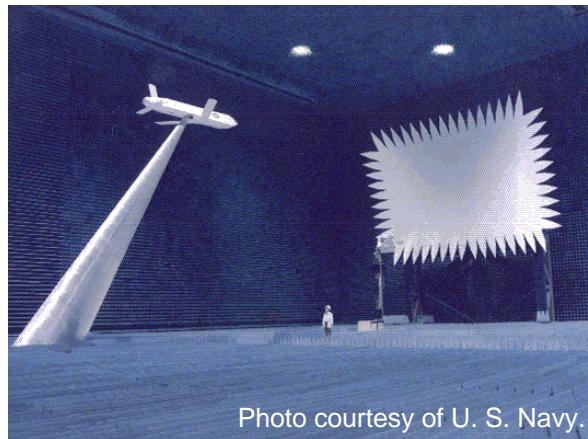
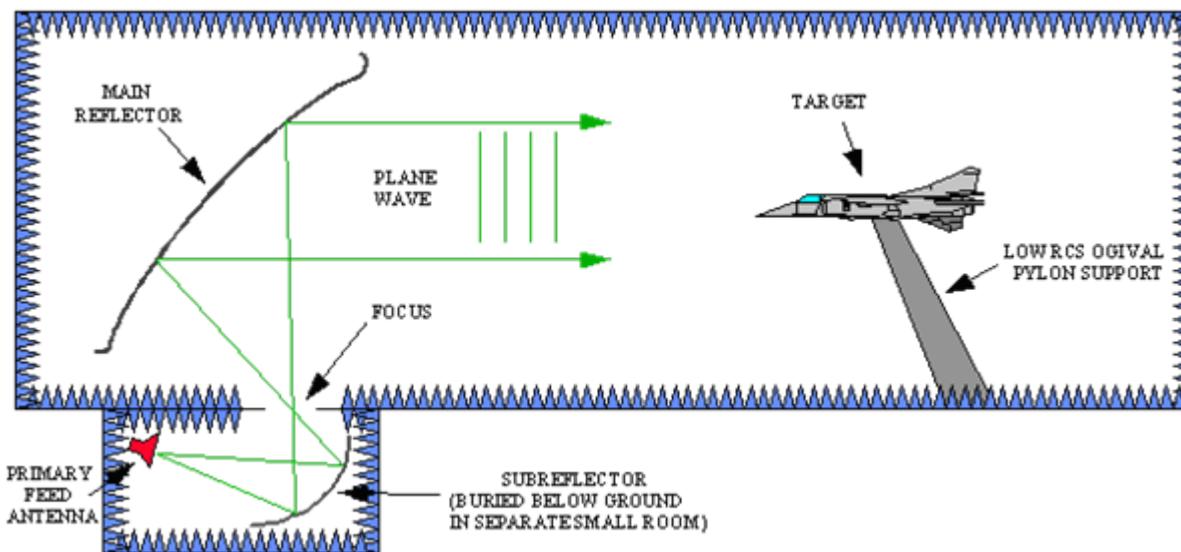


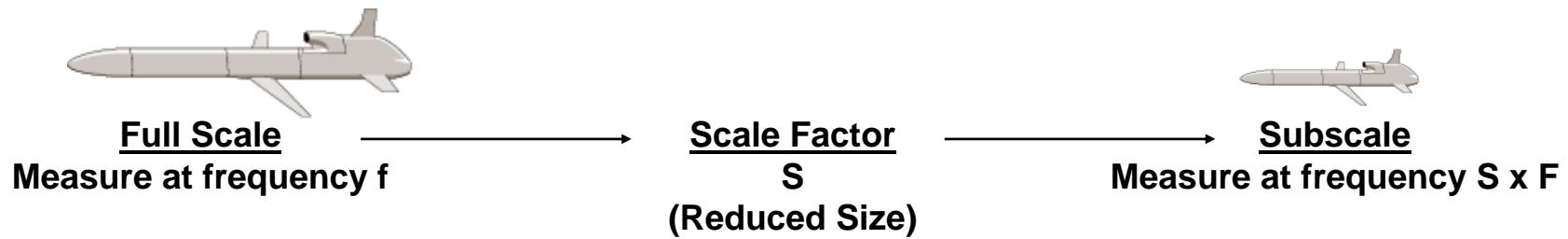
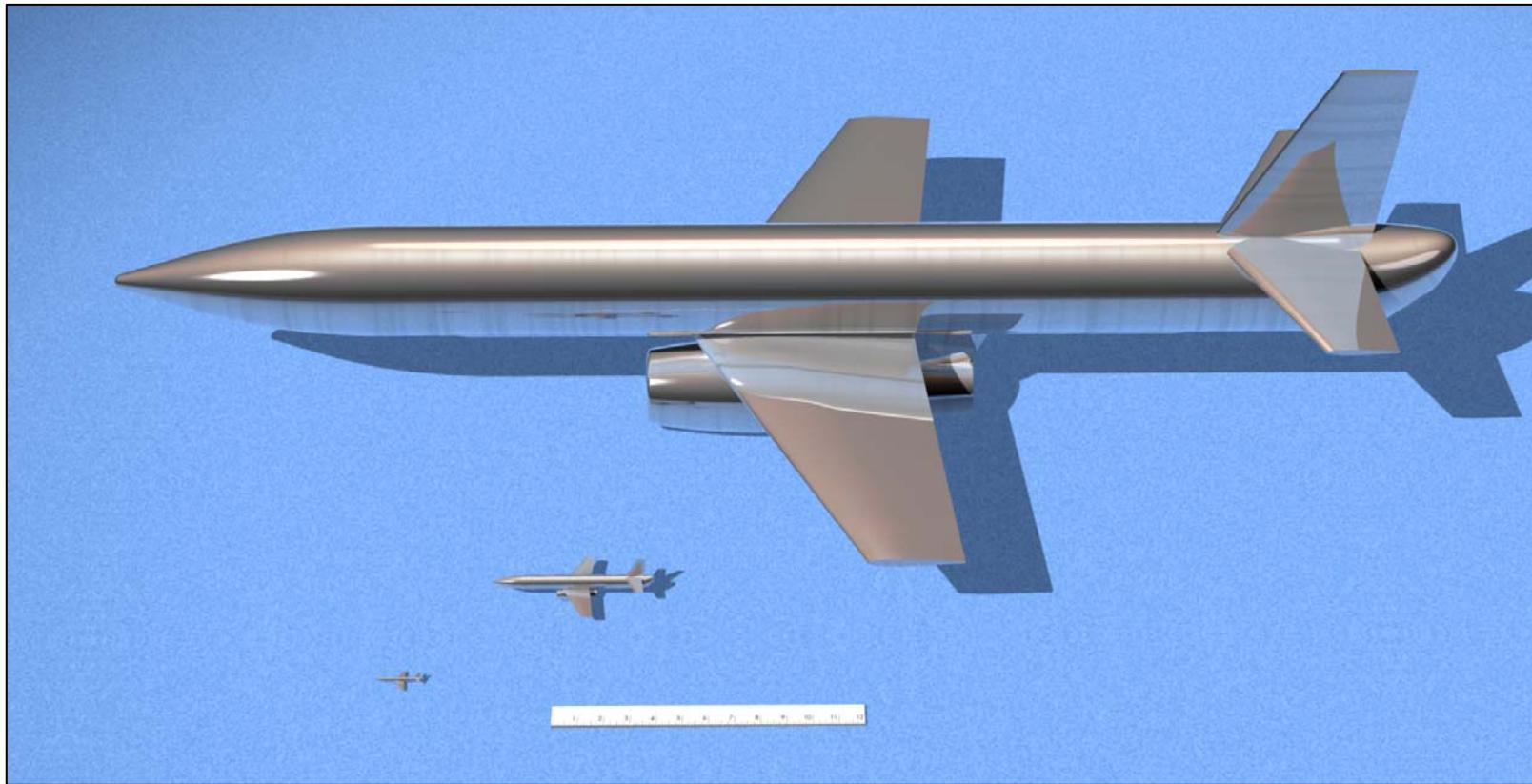
Photo courtesy of U. S. Navy.





Scale Model Measurement

- MQM-107 Drone in 0.29, 0.034, and 0.01 scaled sizes





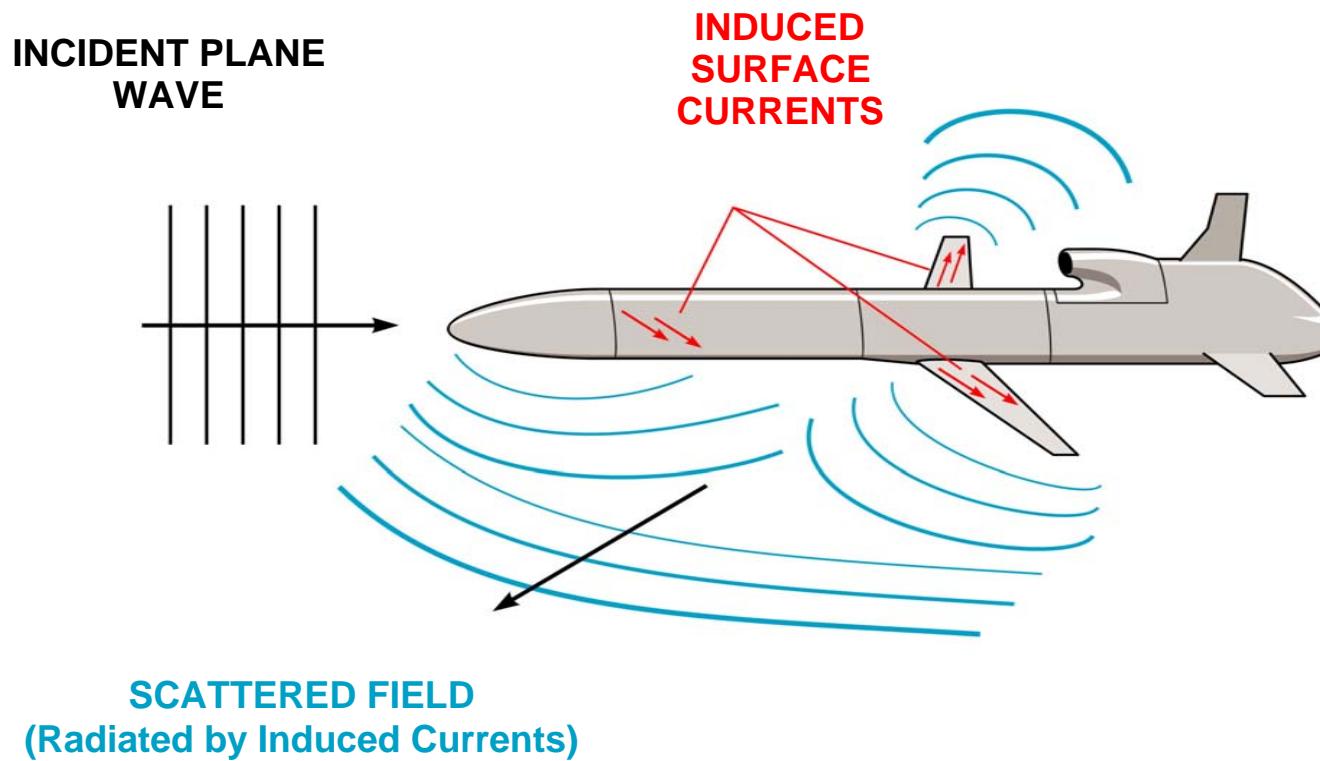
Scaling of Targets for RCS Measurements



QUANTITY	FULL-SCALE	SUBSCALE
LENGTH	L	$L' = L/S$
TIME	t	$t' = t/S$
FREQUENCY	f	$f' = Sf$
WAVELENGTH	λ	$\lambda' = \lambda/S$
CONDUCTIVITY	g	$g' = Sg$
PERMITTIVITY	ϵ	$\epsilon' = \epsilon$
PERMEABILITY	μ	$\mu' = \mu$
RCS	σ	$\sigma' = \sigma/S^2$



Electromagnetic Scattering

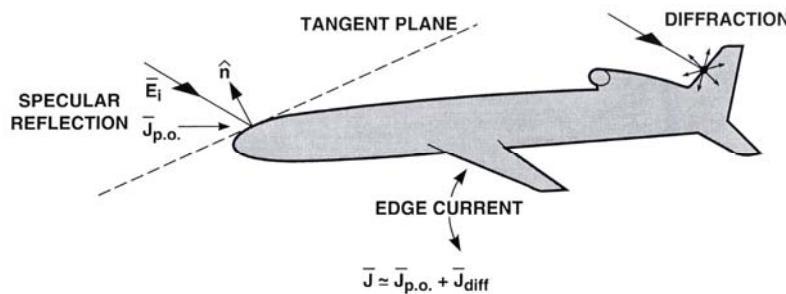


- **TWO STEP PROCESS TO DETERMINE SCATTERED FIELD**
 - DETERMINE INDUCED SURFACE CURRENTS
 - CALCULATE FIELD RADIATED BY CURRENTS



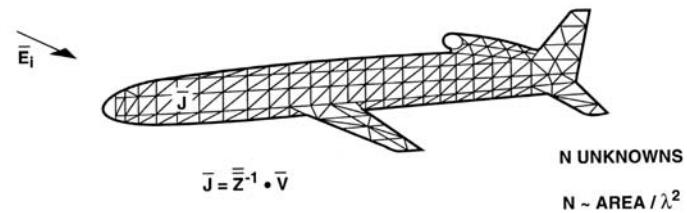
RCS Prediction Approaches

- High frequency approximations
 - Physical theory of diffraction



- Advantages
 - Reduced computational requirements
 - Arbitrary, complex geometries
- Disadvantages
 - Neglects some scattering
 - Applicable only to large, smooth geometries
- Codes
 - Xpatch

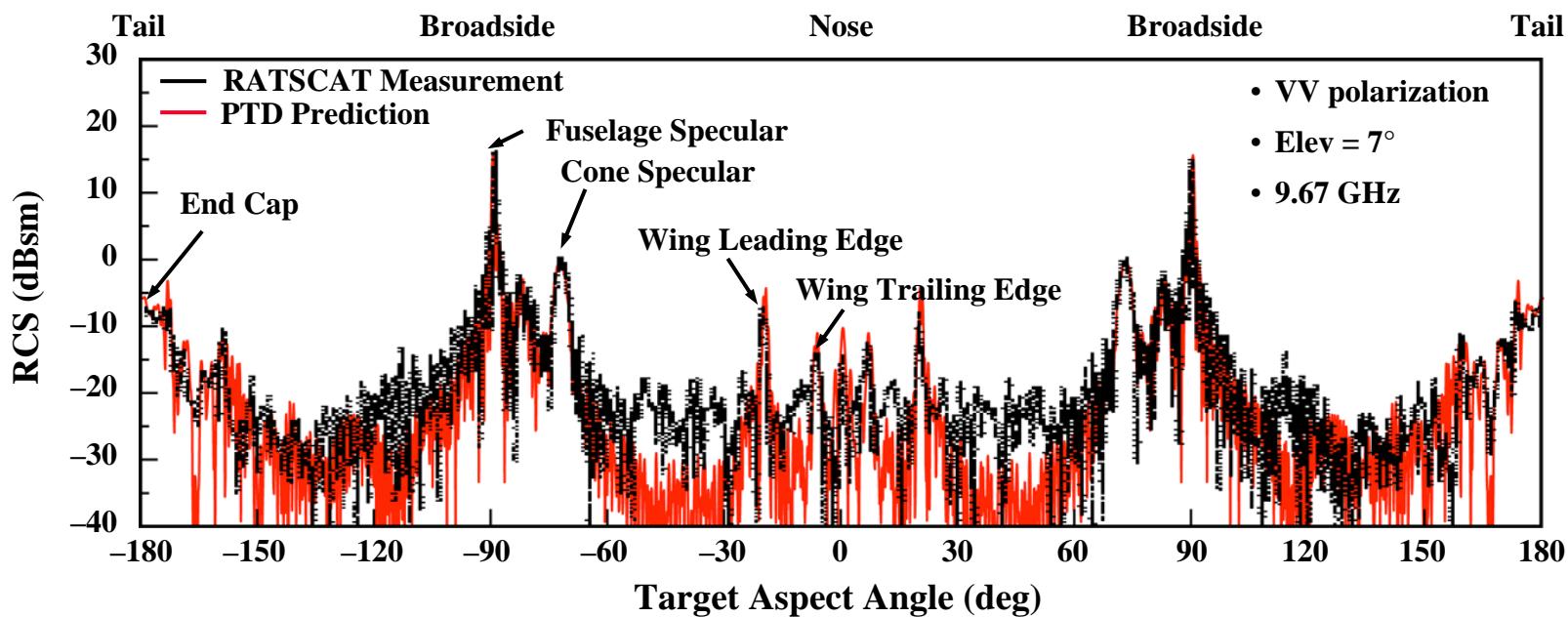
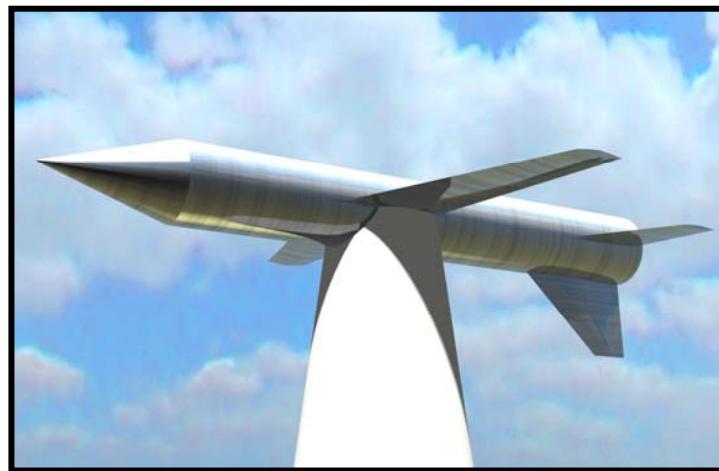
- Exact numerical approaches
 - Method of Moments



- Advantages
 - Exact formulation
- Disadvantages
 - Computationally intensive
- Codes
 - CARLOS
 - CICERO (Body of revolution)
 - FISC
 - FERM



Measured and Calculated RCS of JGAM





Signature Analysis Approaches

- X-band air vehicle targets

		Measurement		Prediction	
		Full Scale	Subscale	High Frequency	Exact
Applicability	Body Shape				
	Surface Details				
	Inlet/Exhaust				
	Materials				
	Antennas				
	Cost				

No issues Some Issues Significant Issues



Summary

- Radar cross section varies significantly across targets of potential interest
 - Depends on target characteristics (shape, material, etc.)
 - Depends on radar parameters (frequency, polarization, etc.)
- Target signature contains several contributors
 - Structural (body shape, surface details, etc.)
 - Propulsion (inlets, exhaust)
 - Avionics (seekers, communication antennas, etc.)
- Accurate estimation of target signatures should draw upon all available tools (i.e. measurement and prediction)
 - Component based signature estimation allows use of multiple tools in coherent roll-up of overall vehicle signature



References

- Atkins, R., Radar Cross Section Tutorial, 1999 IEEE National Radar Conference, 22 April 1999,
- Skolnik, M., Introduction to Radar Systems, New York, McGraw-Hill, 3rd Edition, 2001