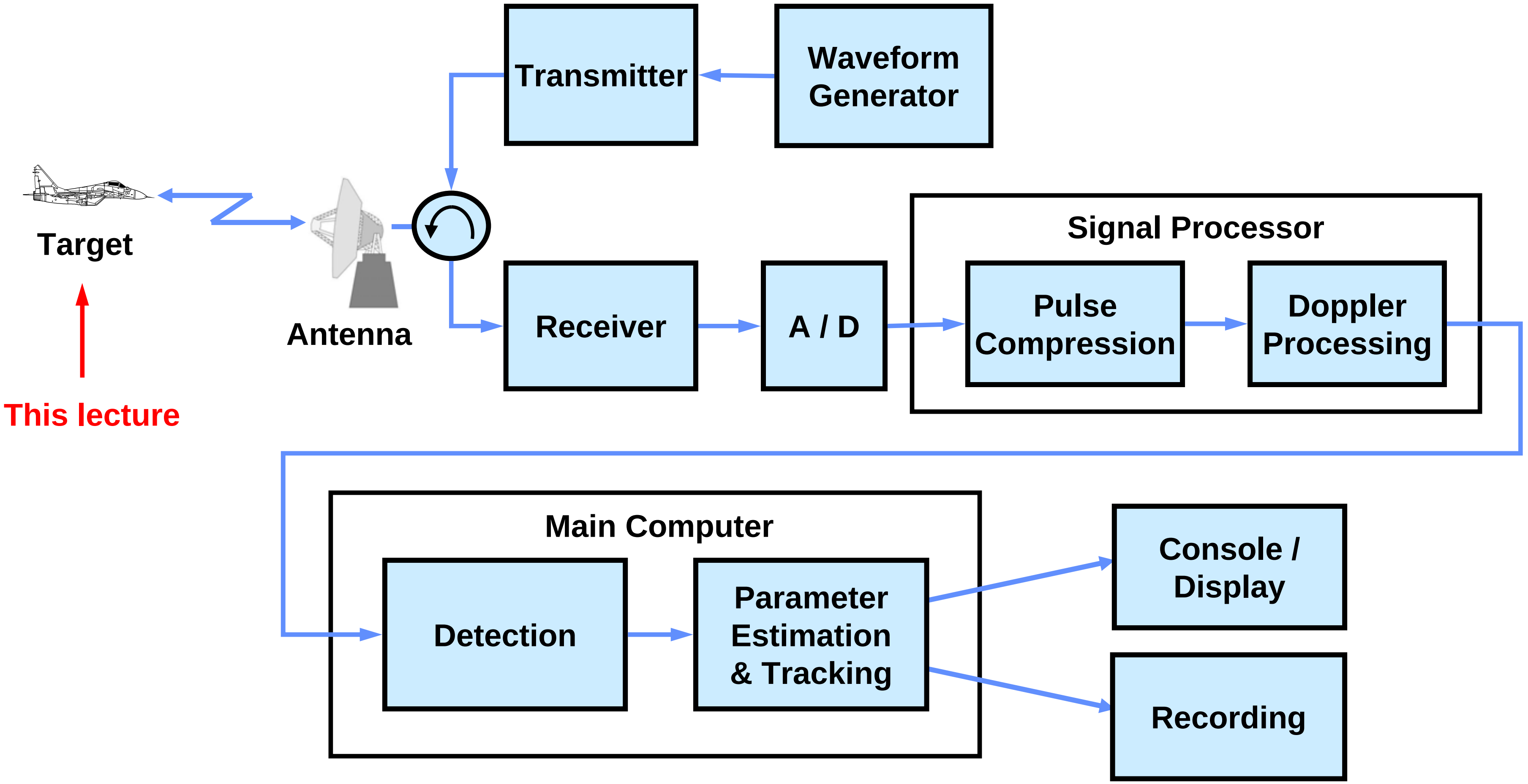
Introduction to Radar Systems

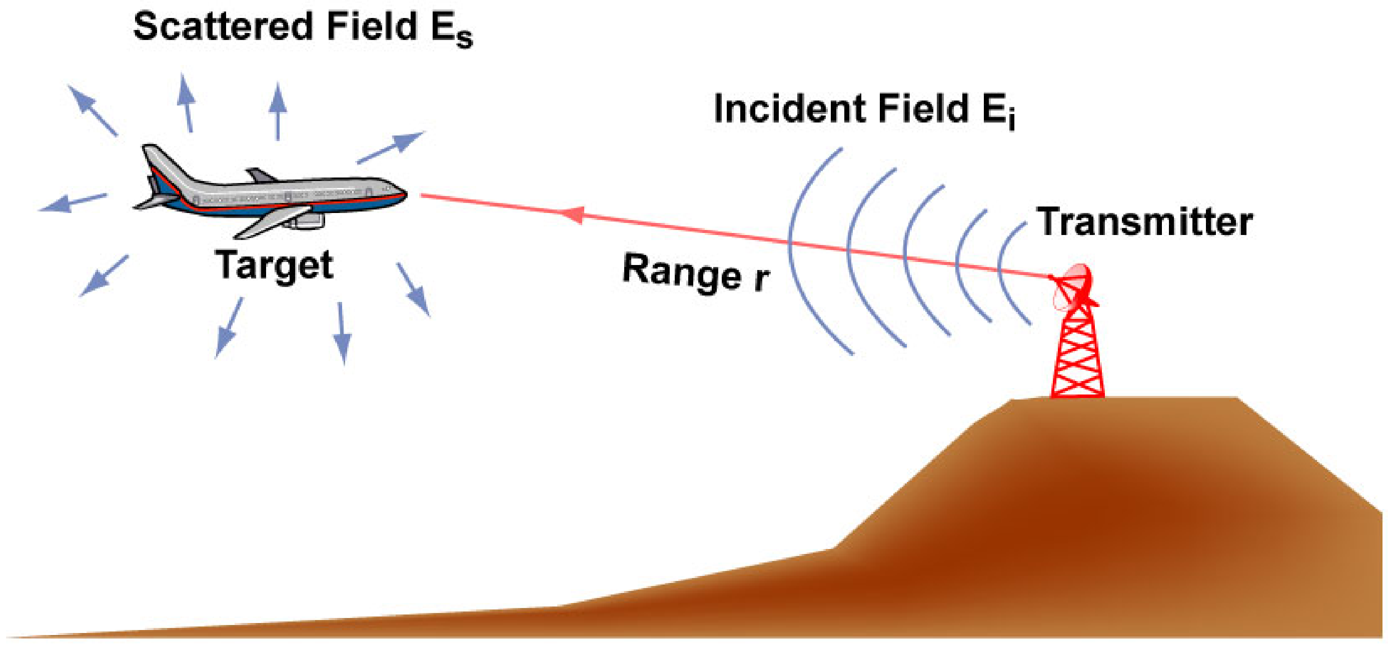
Target Radar Cross Section

Disclaimer of Endorsement and Liability

Generic Radar Block Diagram



Definition of Radar Cross Section (RCS or σ)

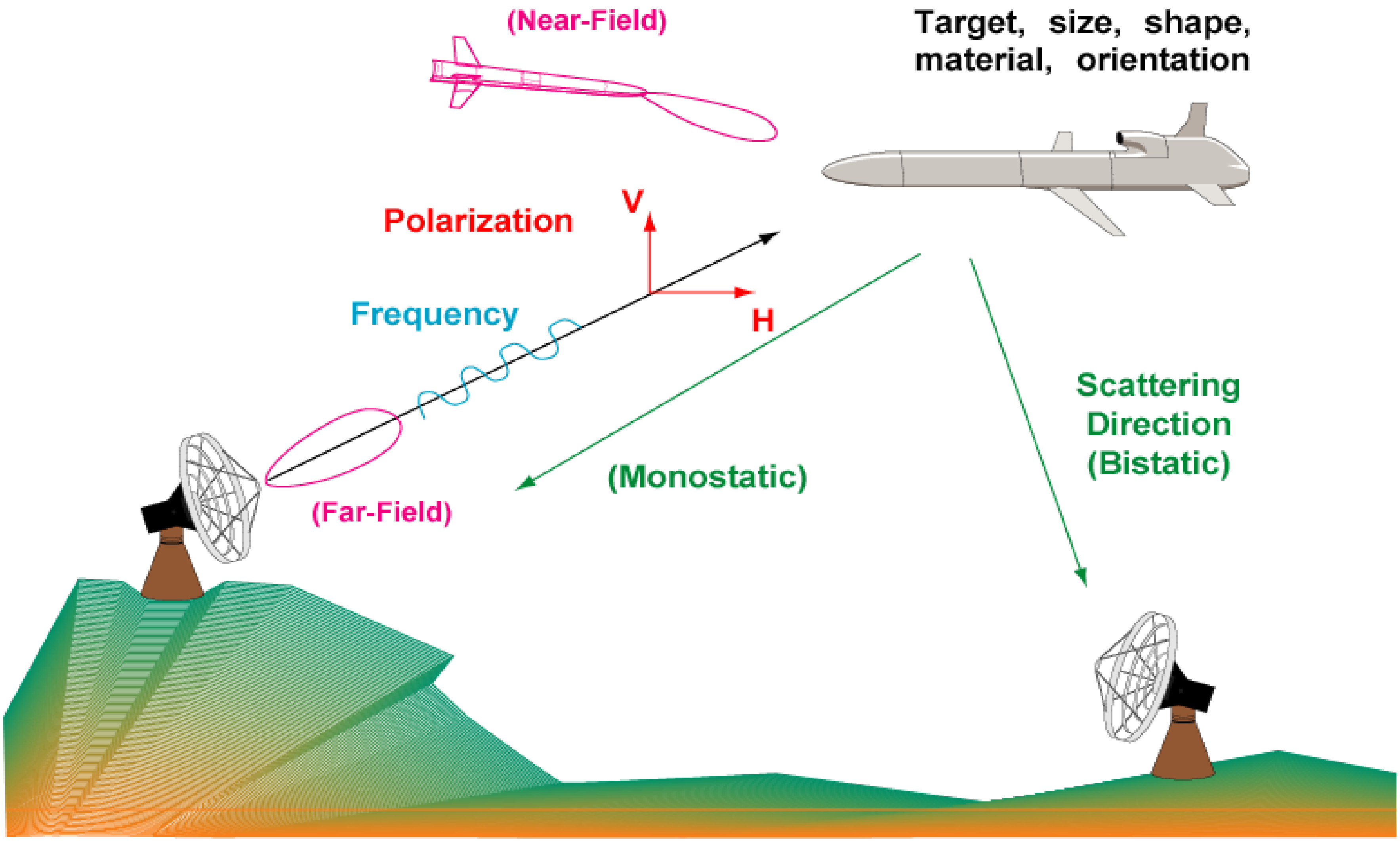


$$RCS = \lim_{r \to \infty} 4\pi r^2 \frac{|E_s|^2}{|E_i|^2} \quad \text{(Unit: Area)}$$

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

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

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

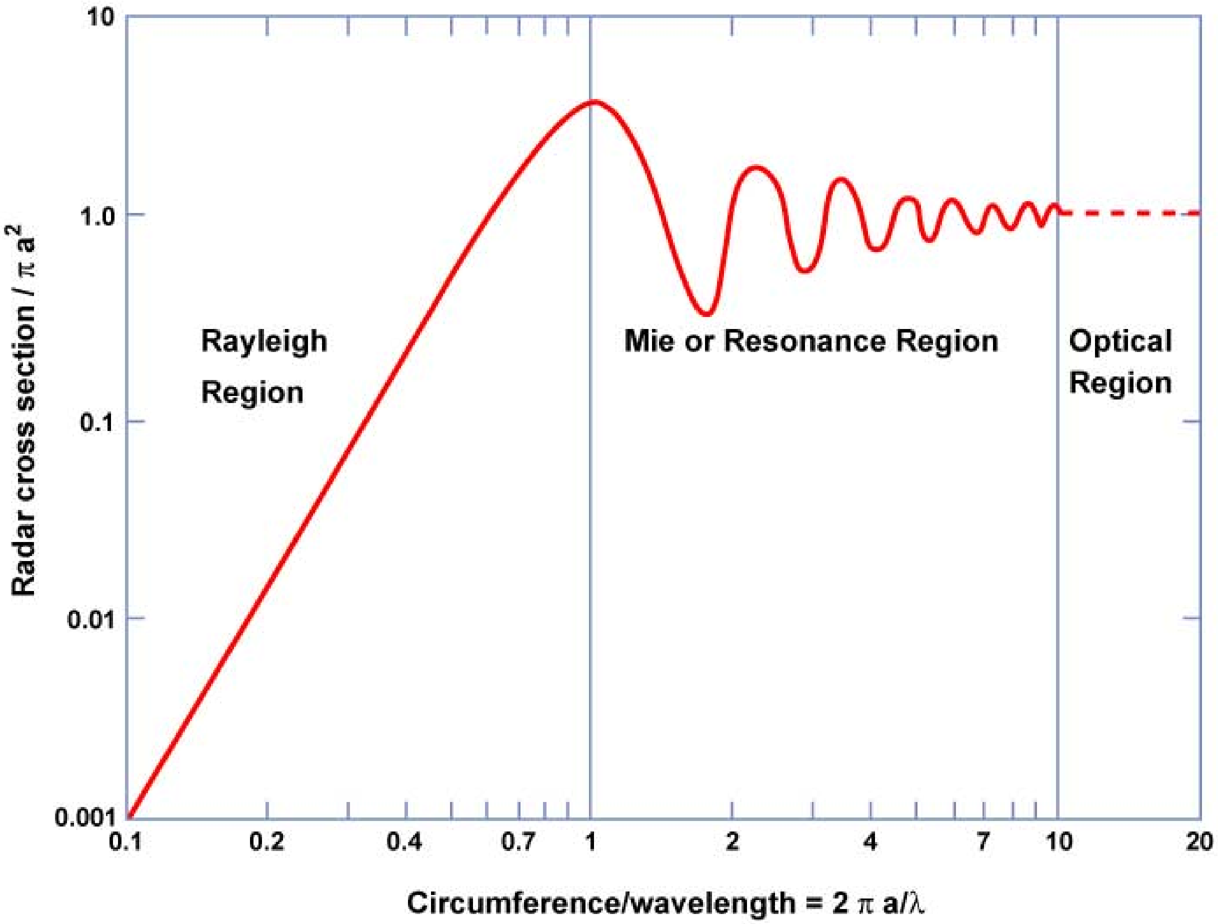


Figure by MIT OCW.

Rayleigh Region

$\lambda >> a$

$\sigma = k / \lambda^4$

Resonance or Mie Region

Oscillations

Backscattered wave interferes with creeping wave

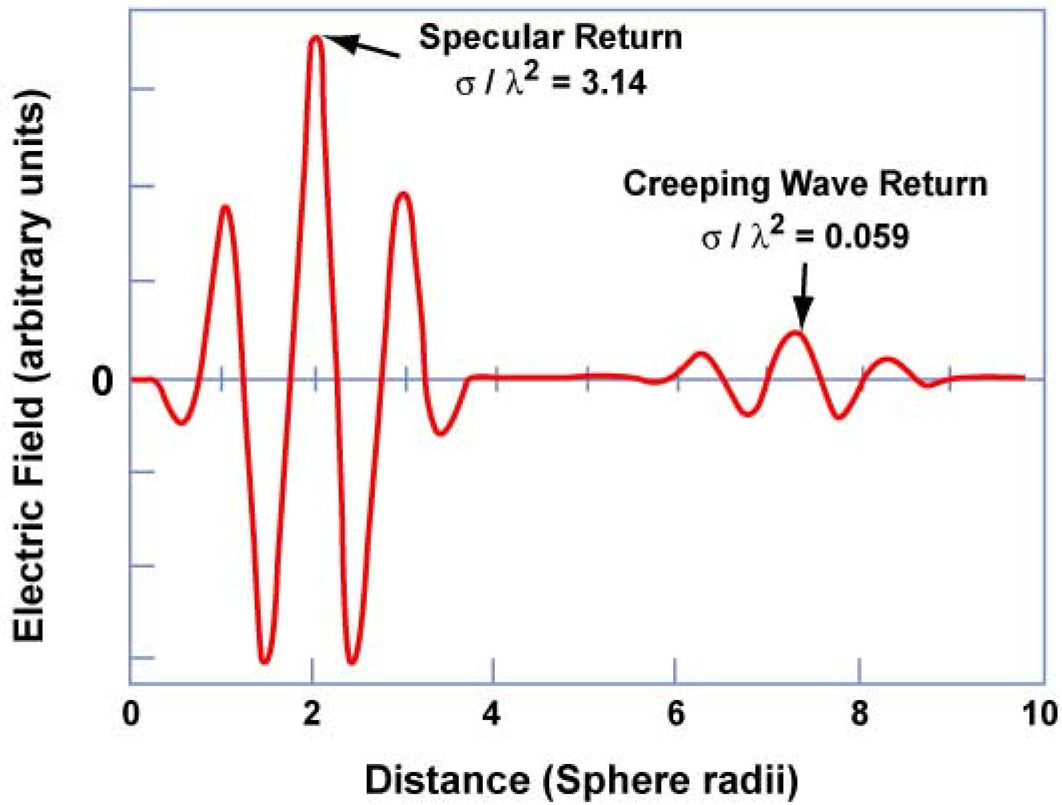
Optical Region

$\lambda << a$

$\sigma = \pi a^2$

Surface and edge scattering occur

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

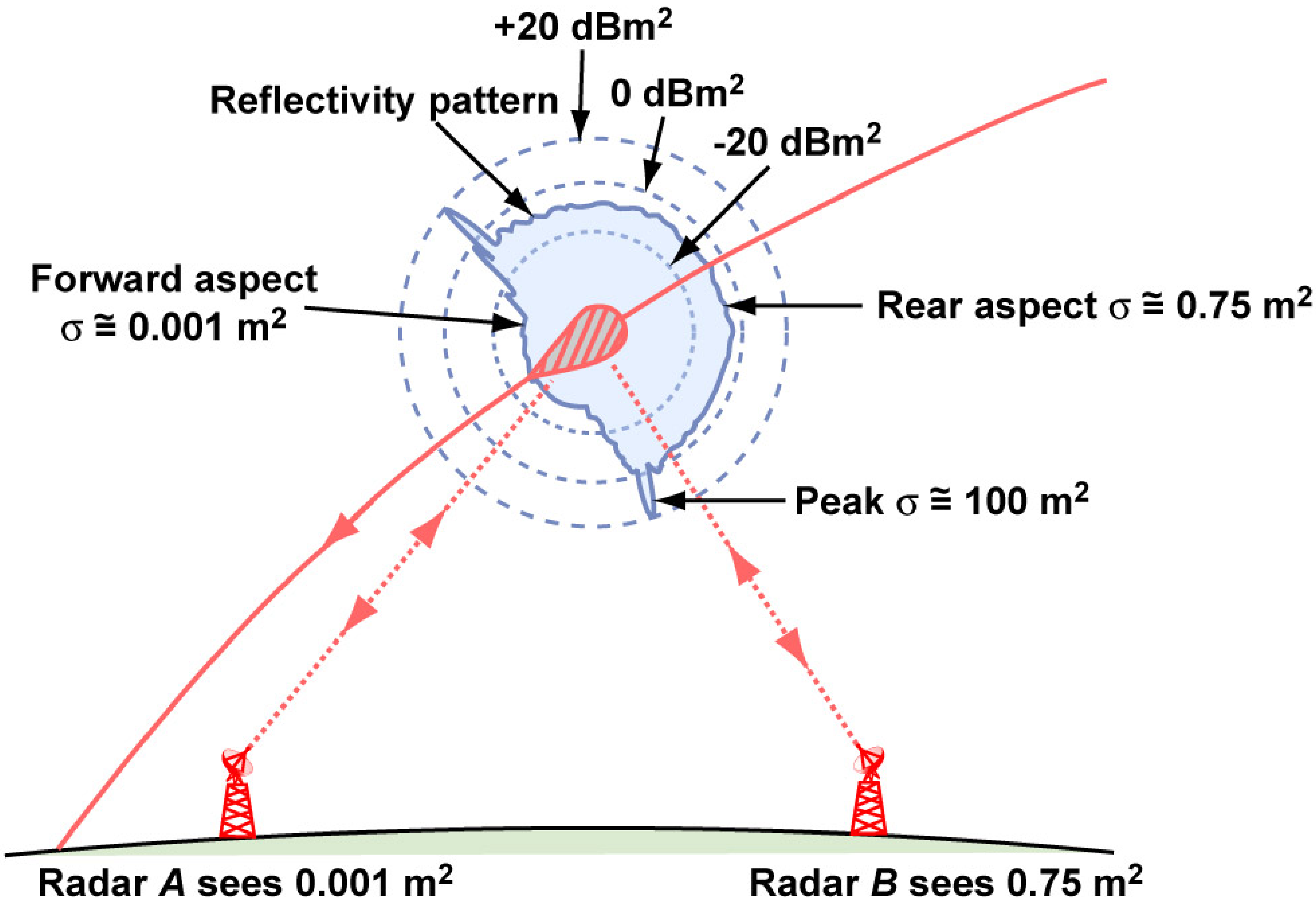


Figure by MIT OCW.

Examples of Radar Cross Sections

	Square meters
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}

Outline

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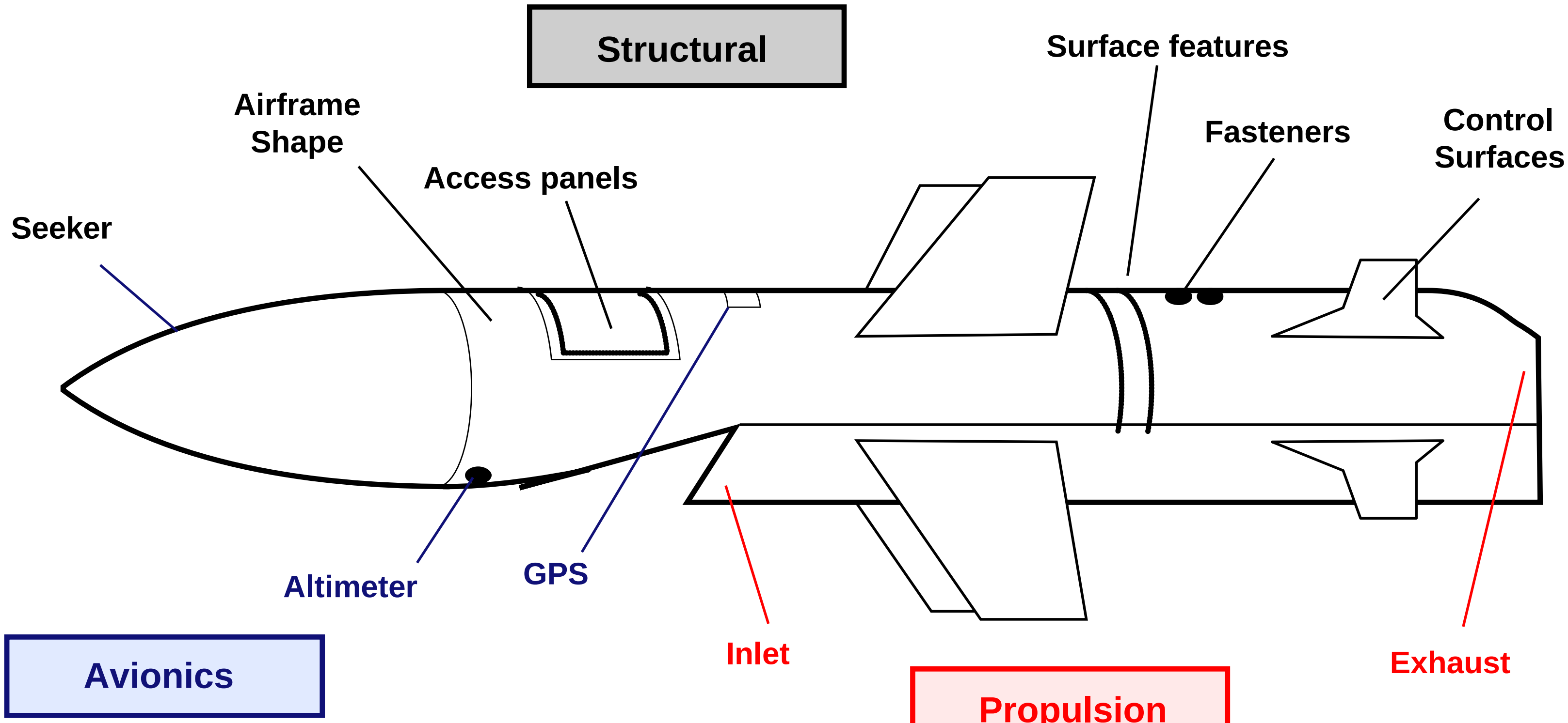
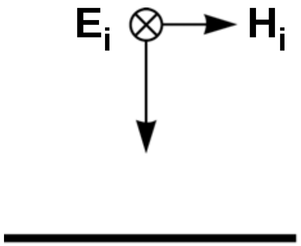
Components of Target RCS



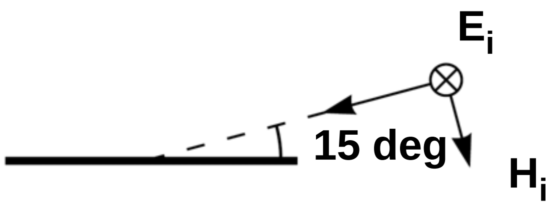
- Three types of RCS contributors:
  - Structural (body shape, control surfaces, etc.)
  - Propulsion (inlets, exhaust, etc.)
  - Avionics (seeker, GPS, altimeter, etc.)

Description of Sample Cases on Video

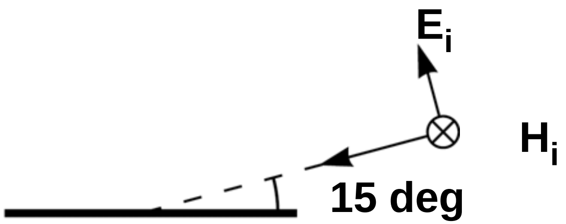
- **Case 1**



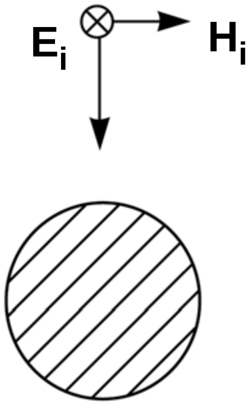
- **Case 2**



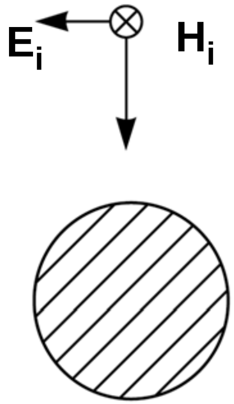
- **Case 3**



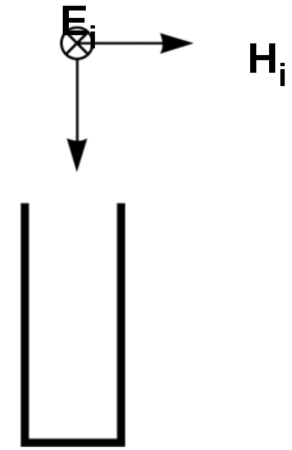
- **Case 4**



- **Case 5**

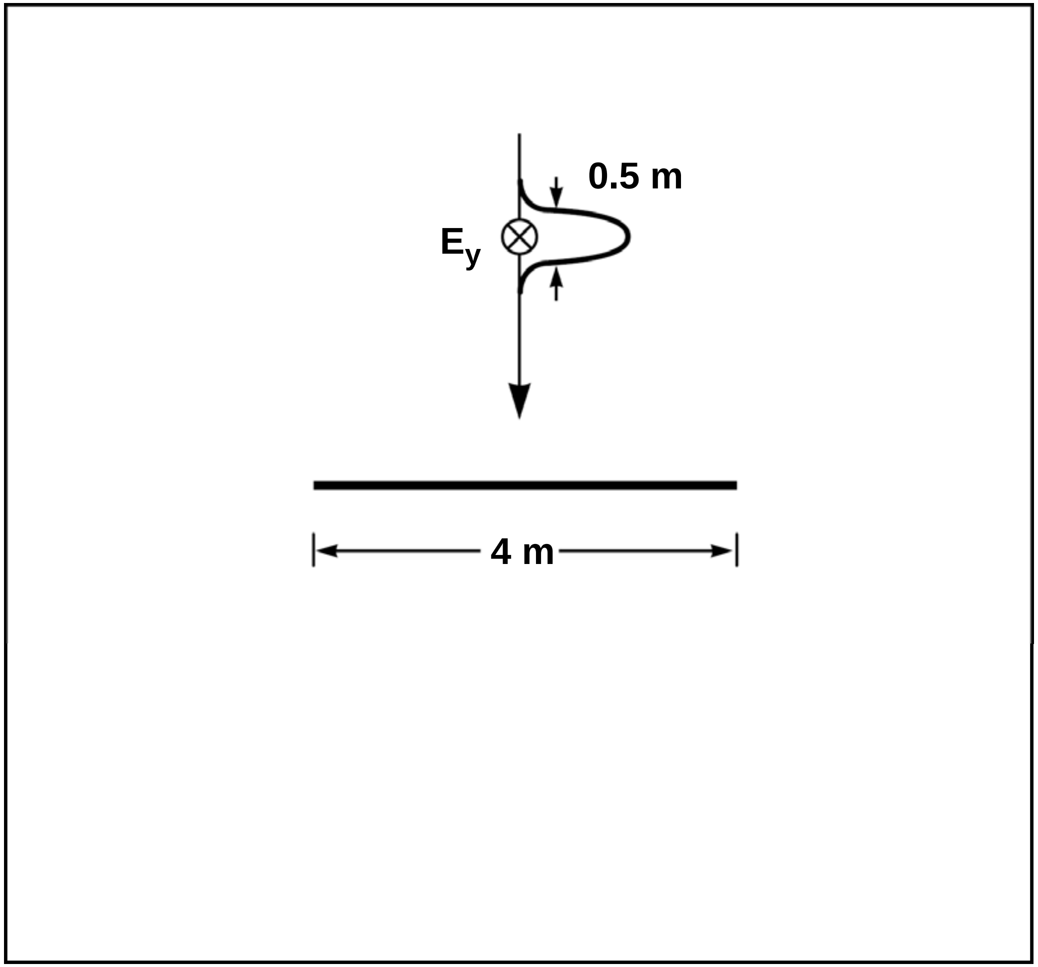


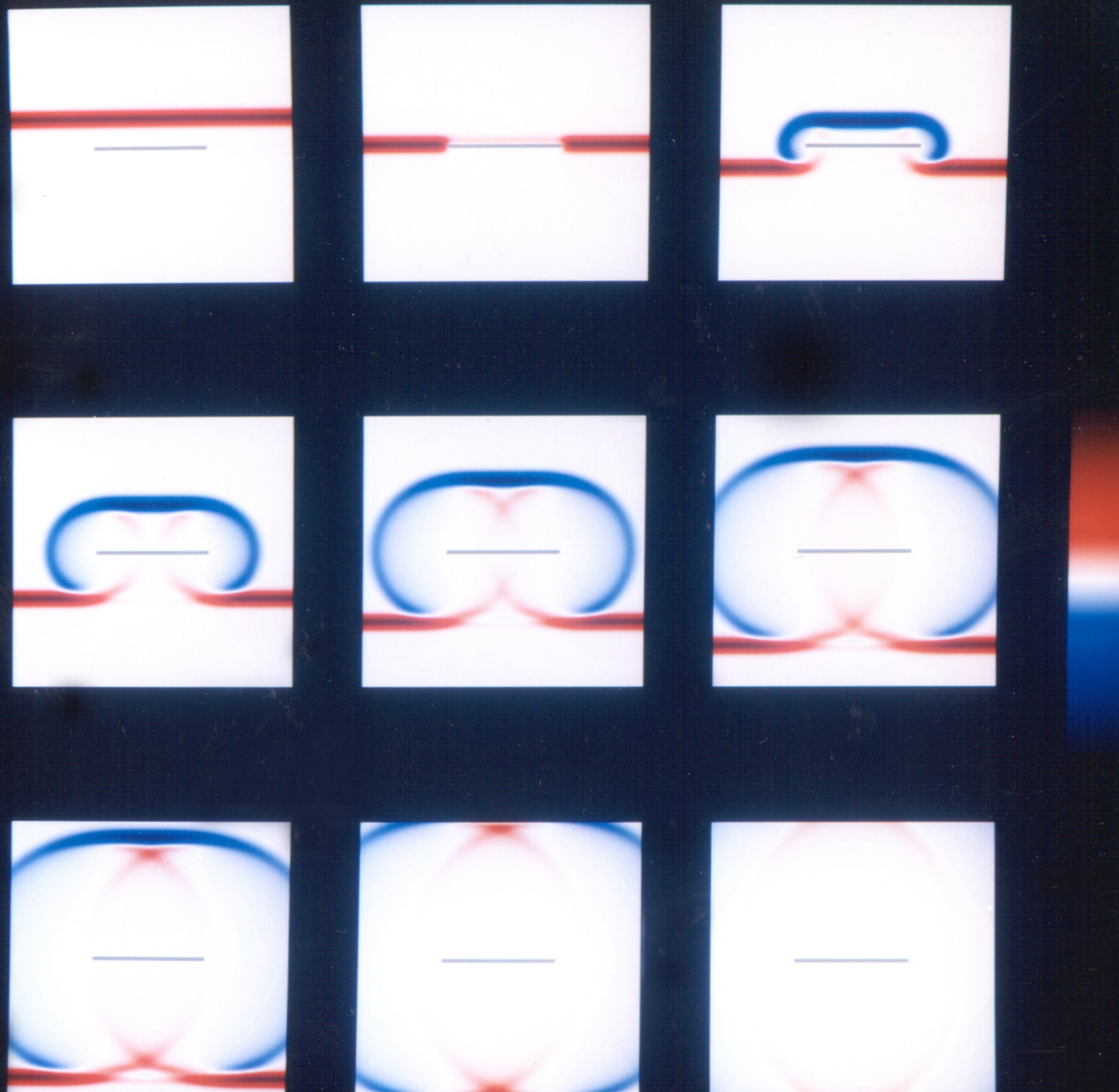
- **Case 6**



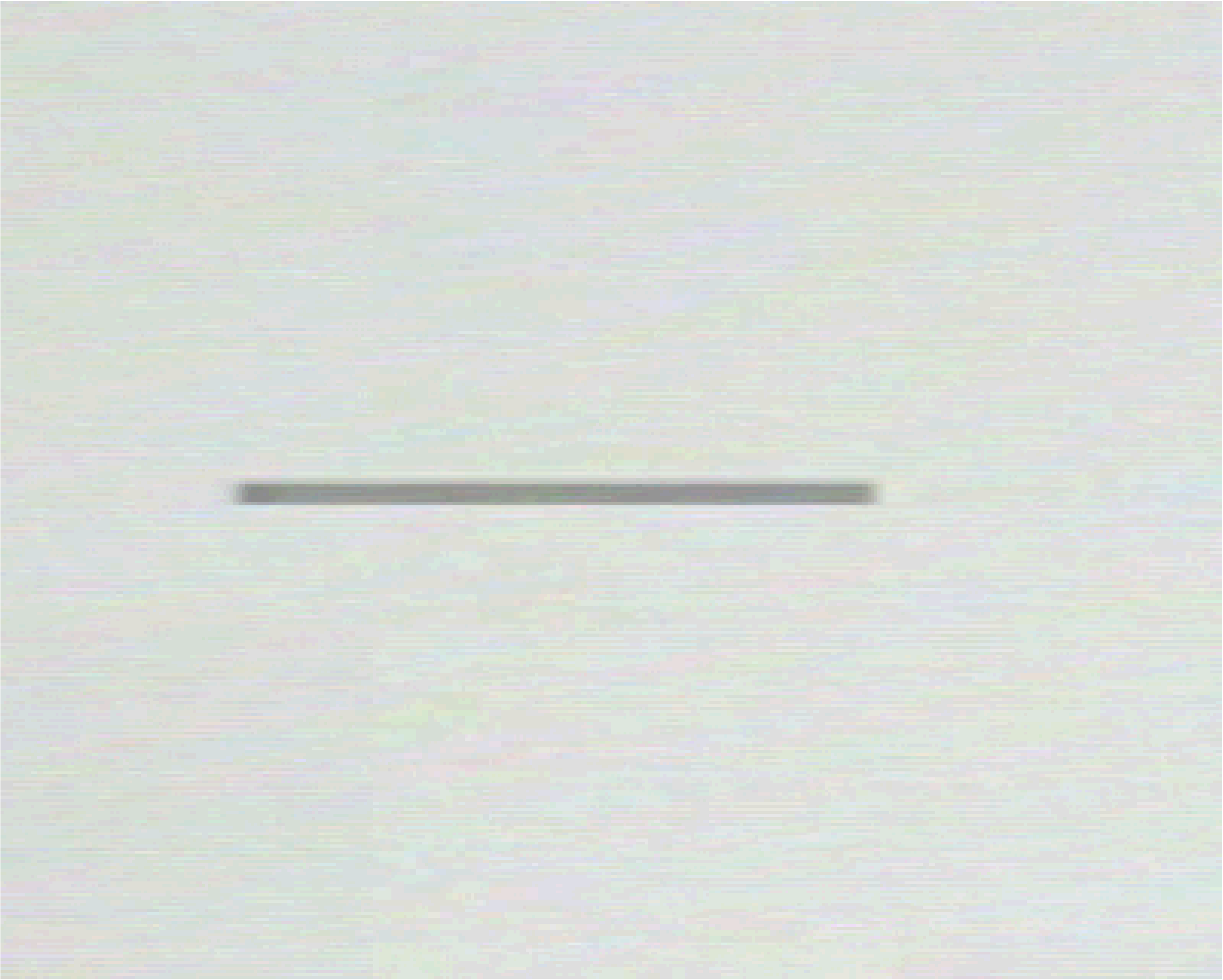
FD-TD Simulation of Scattering by Strip

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



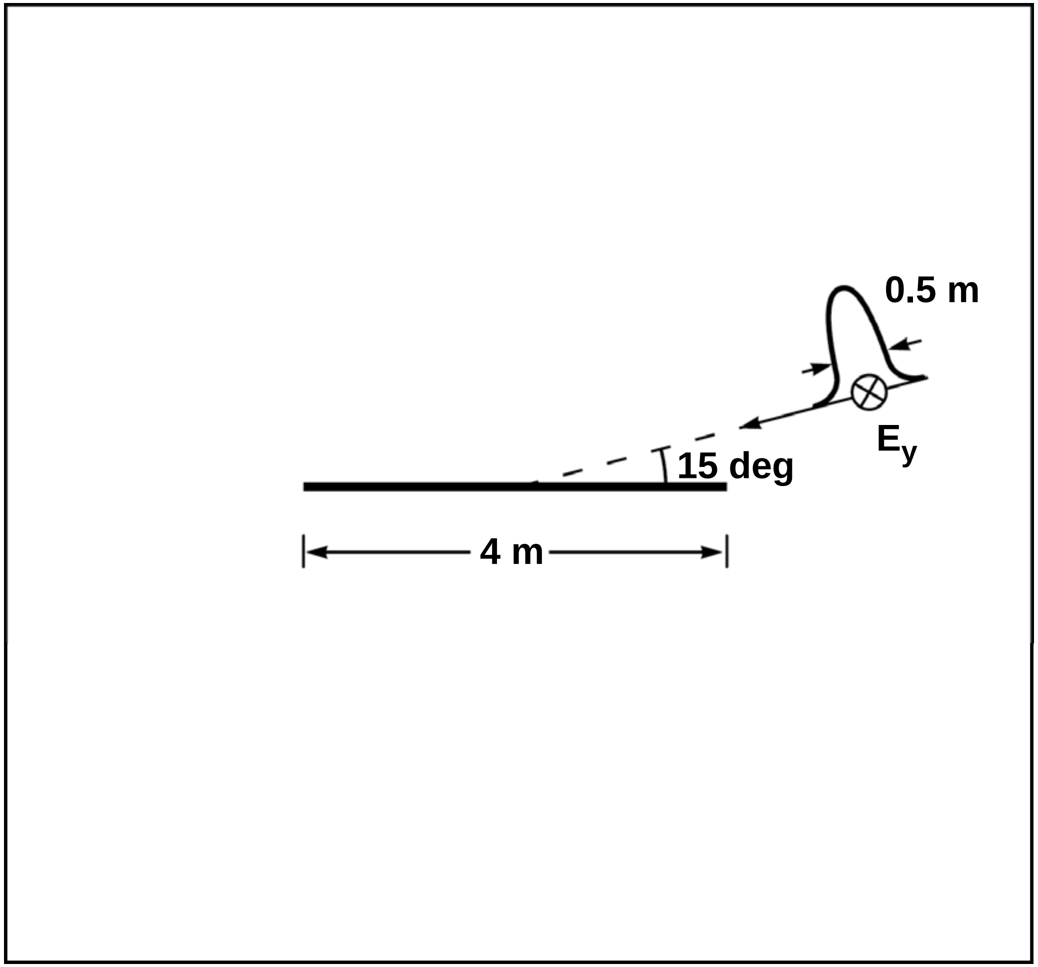


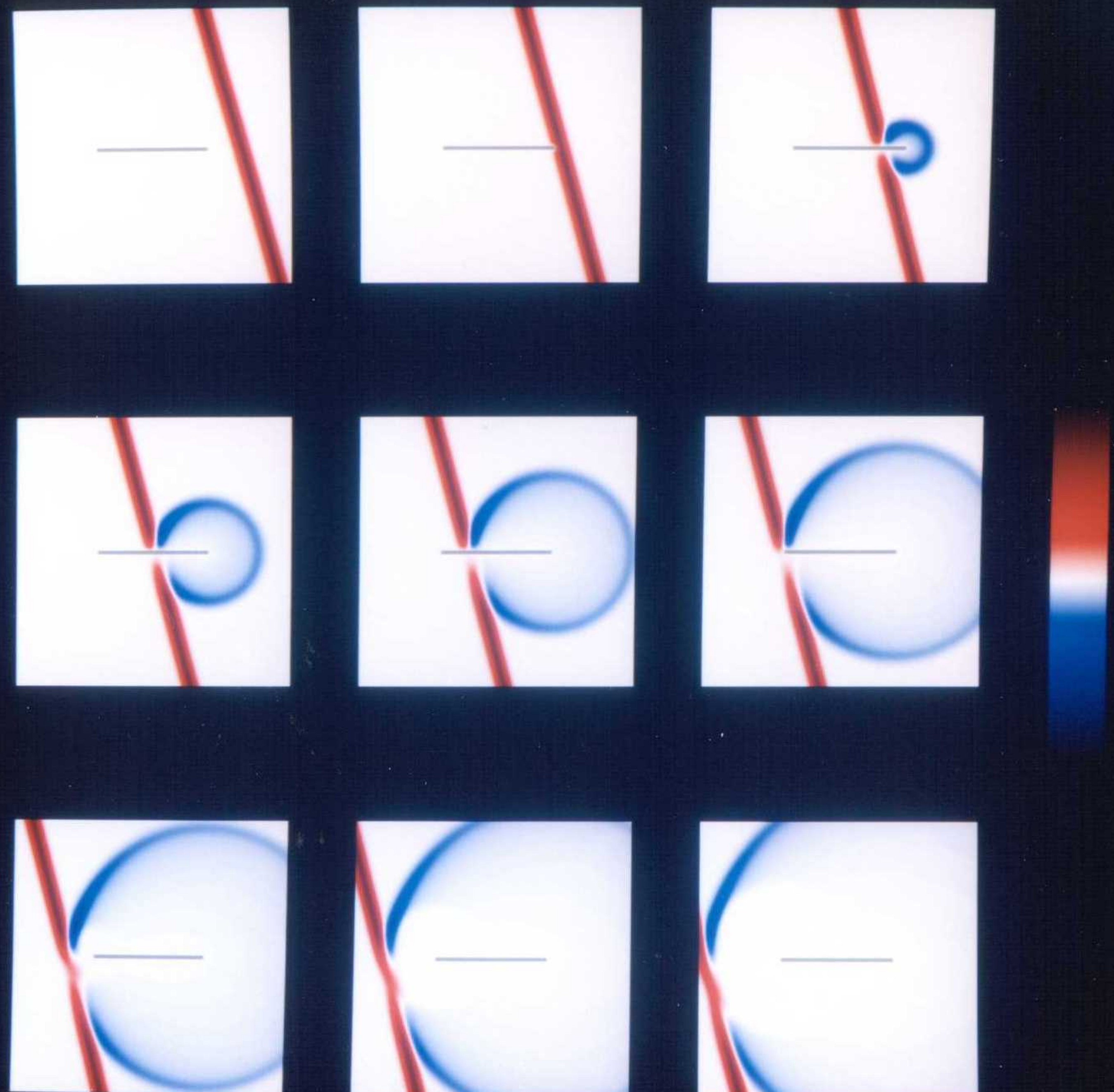
FD-TD Simulation of Scattering by Strip



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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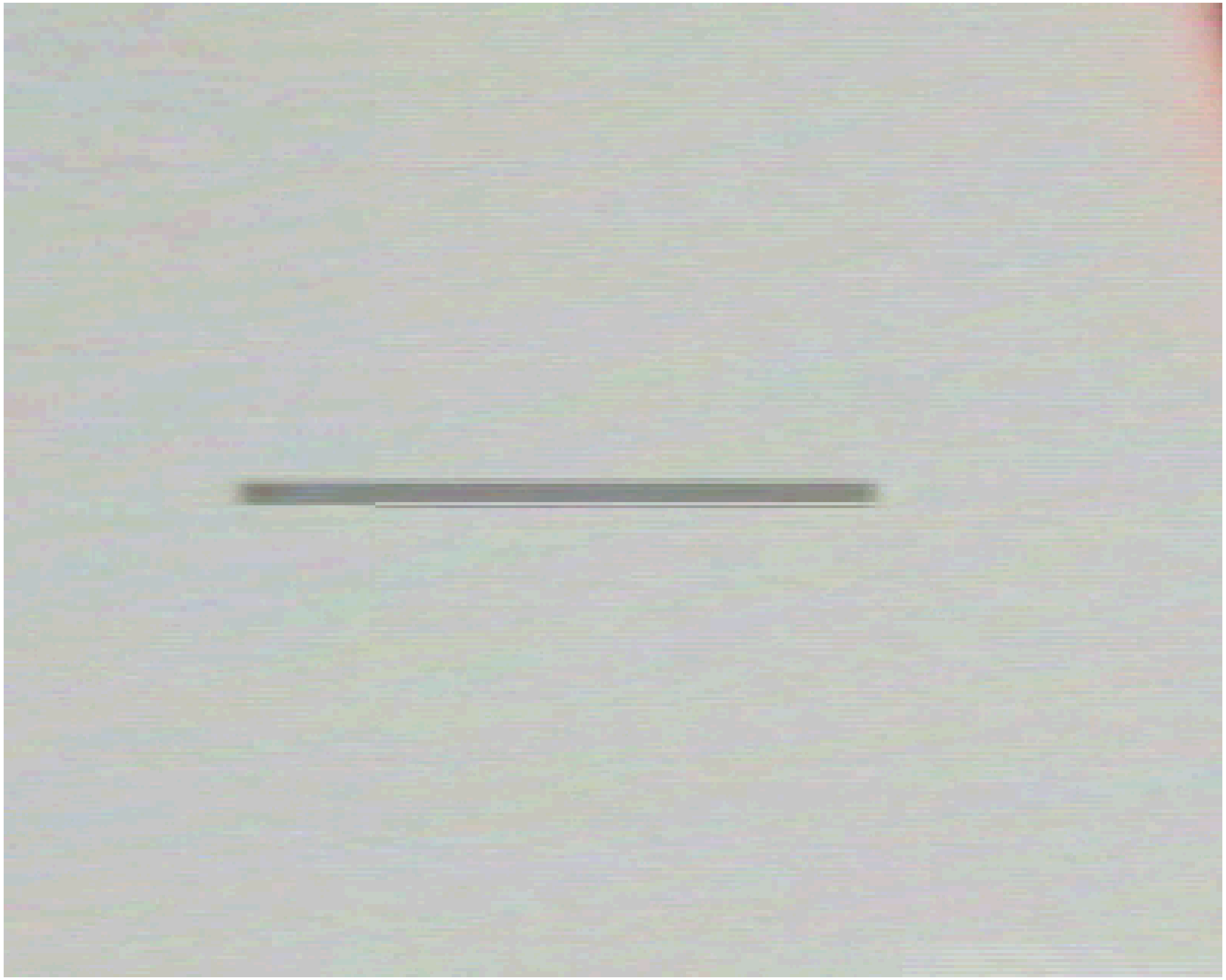
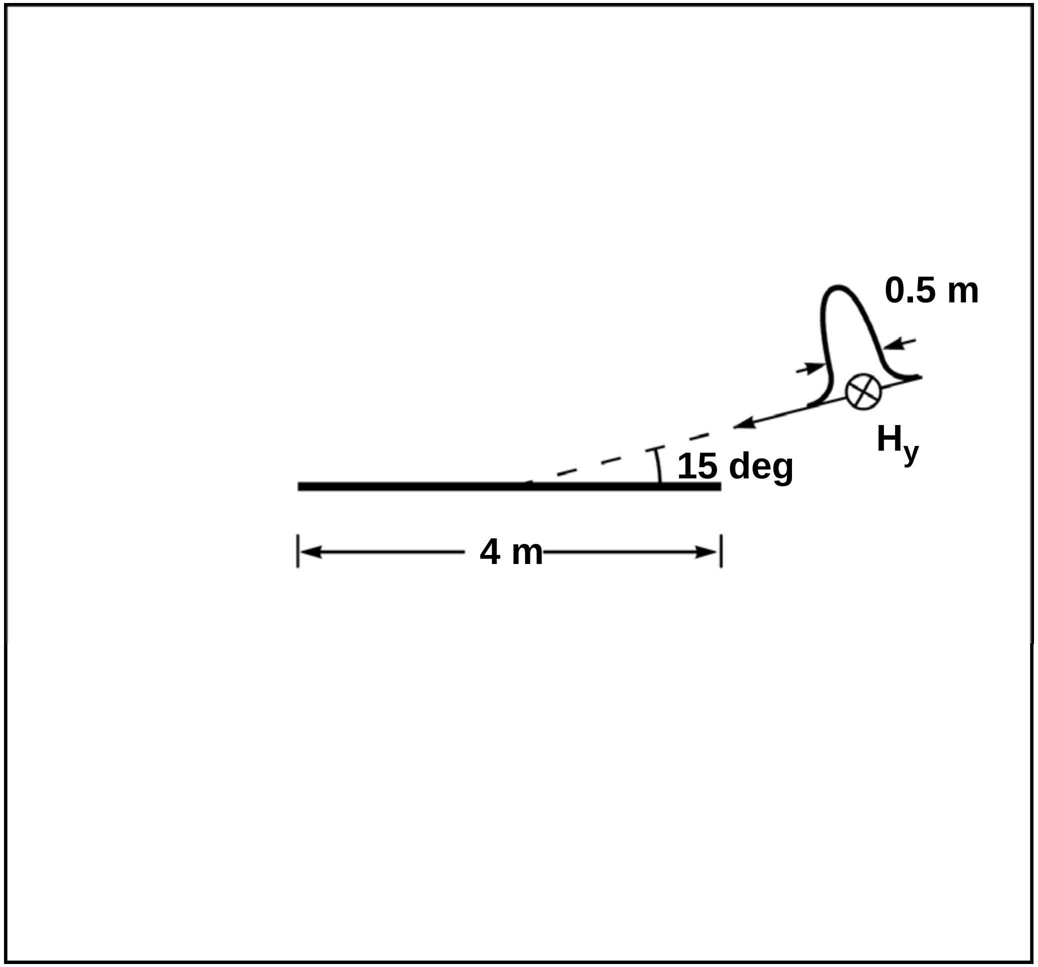
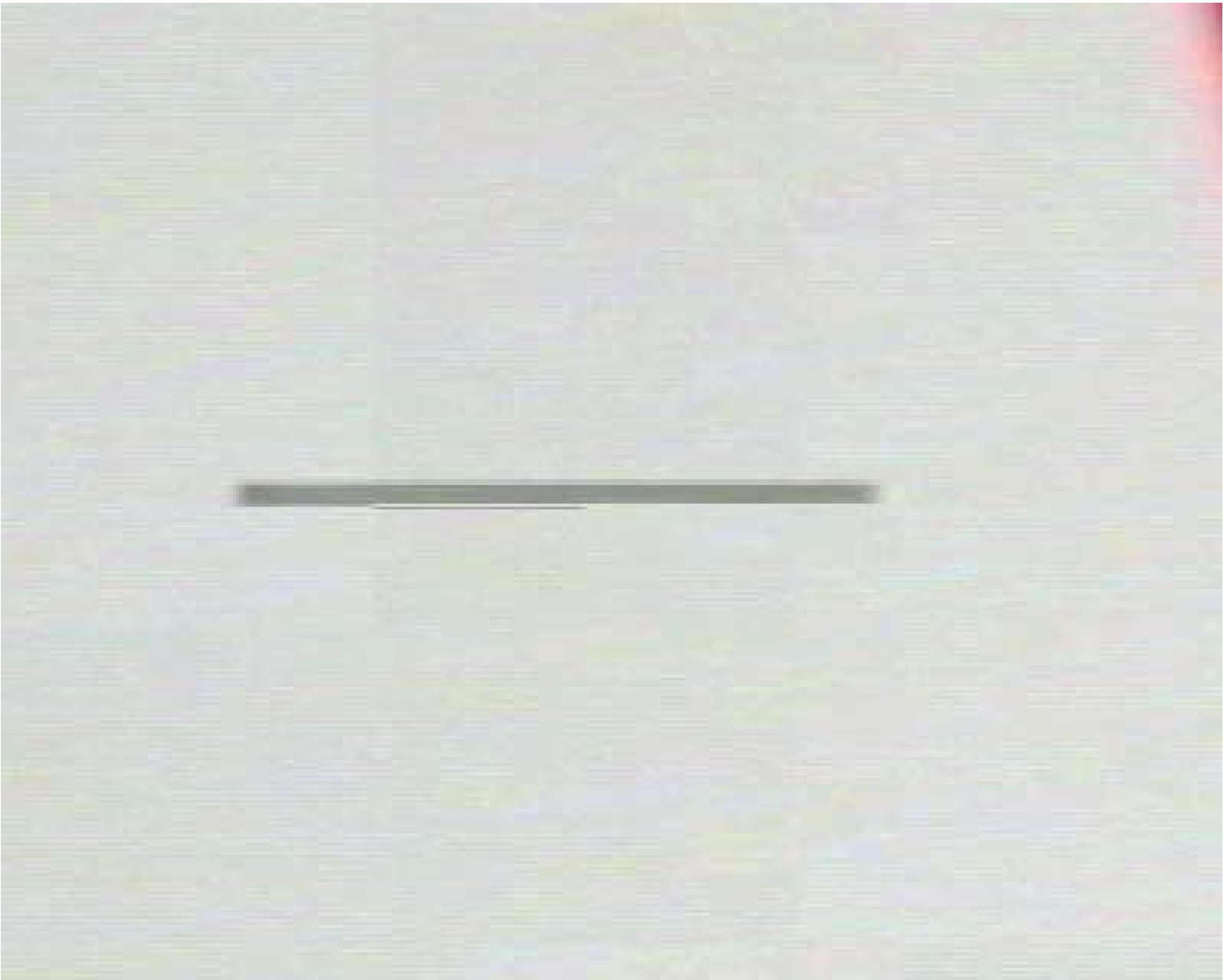


FD-TD Simulation of Scattering by Strip

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

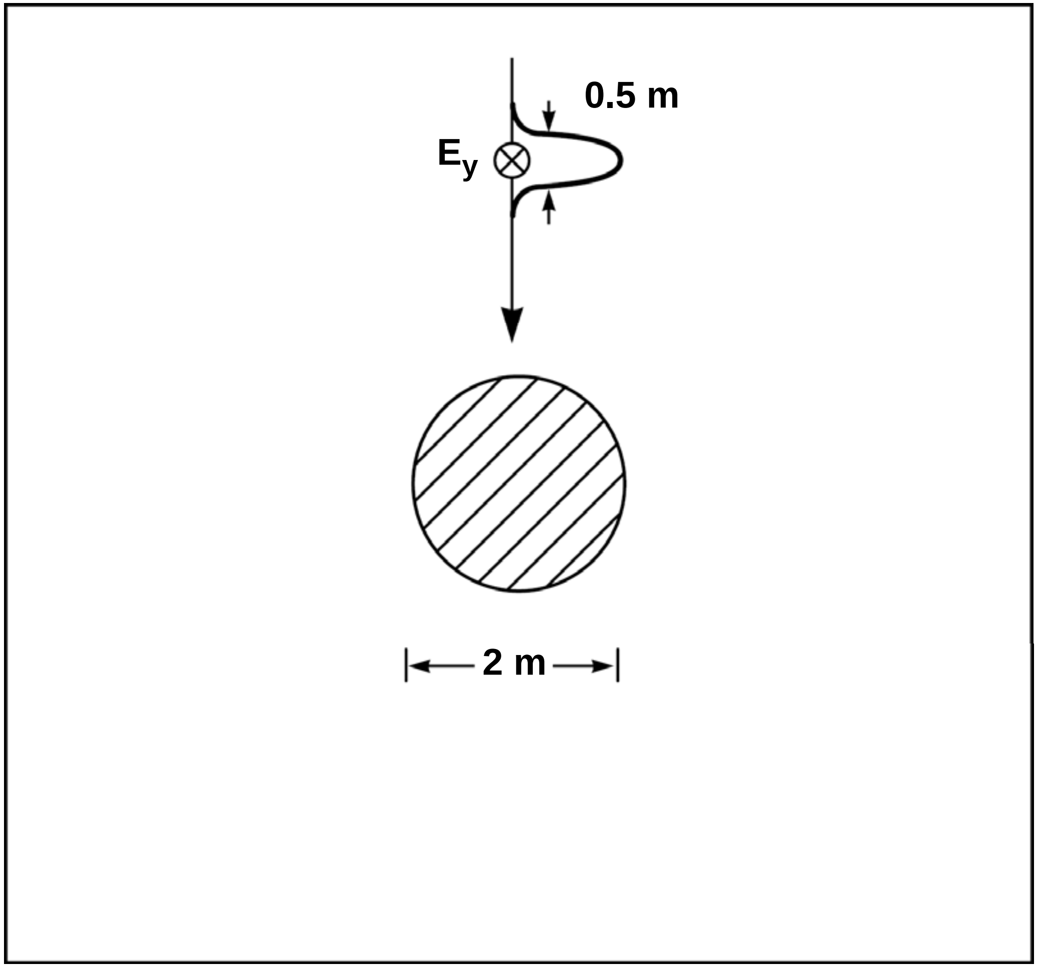


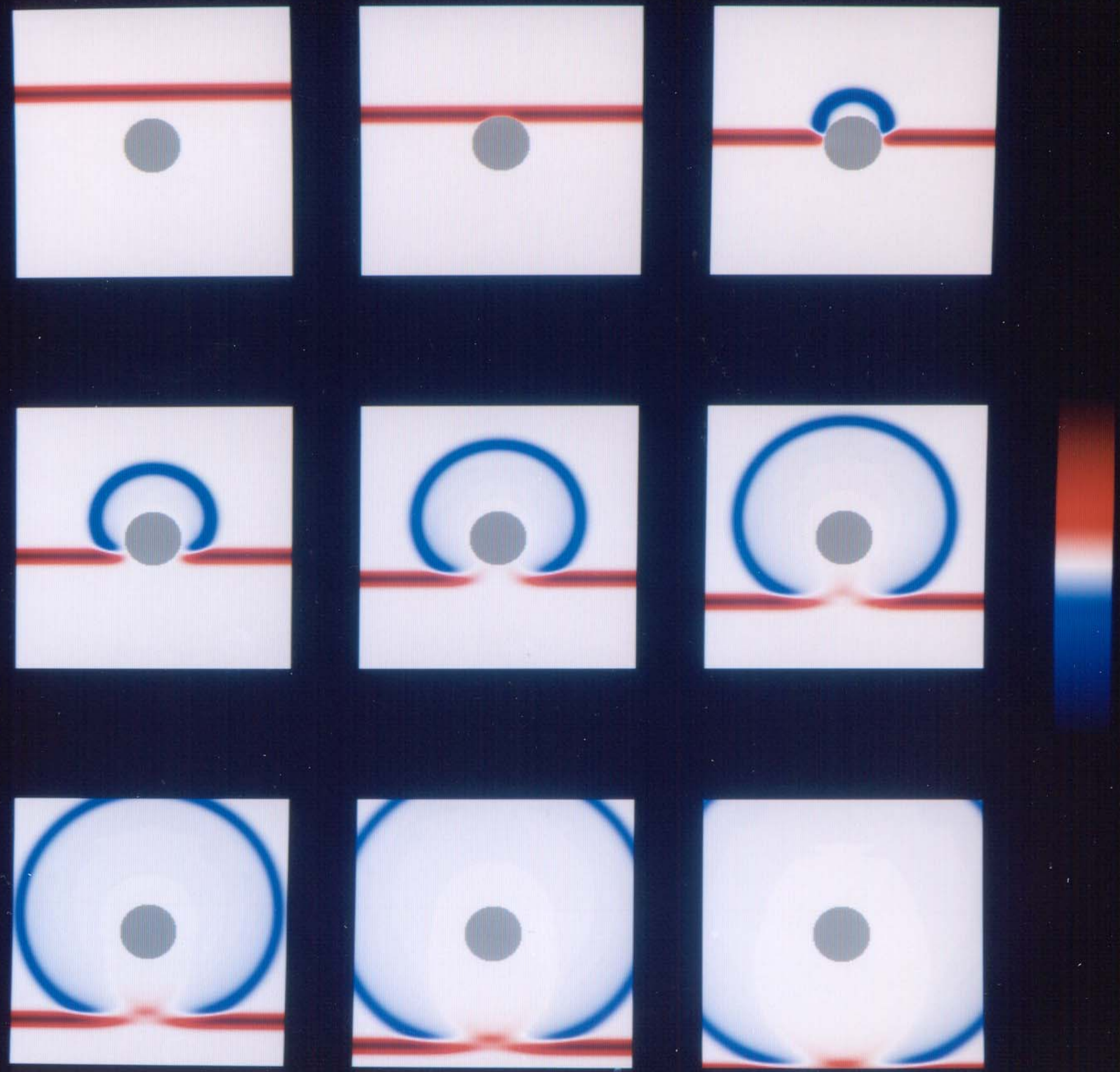
FD-TD Simulation of Scattering by Strip



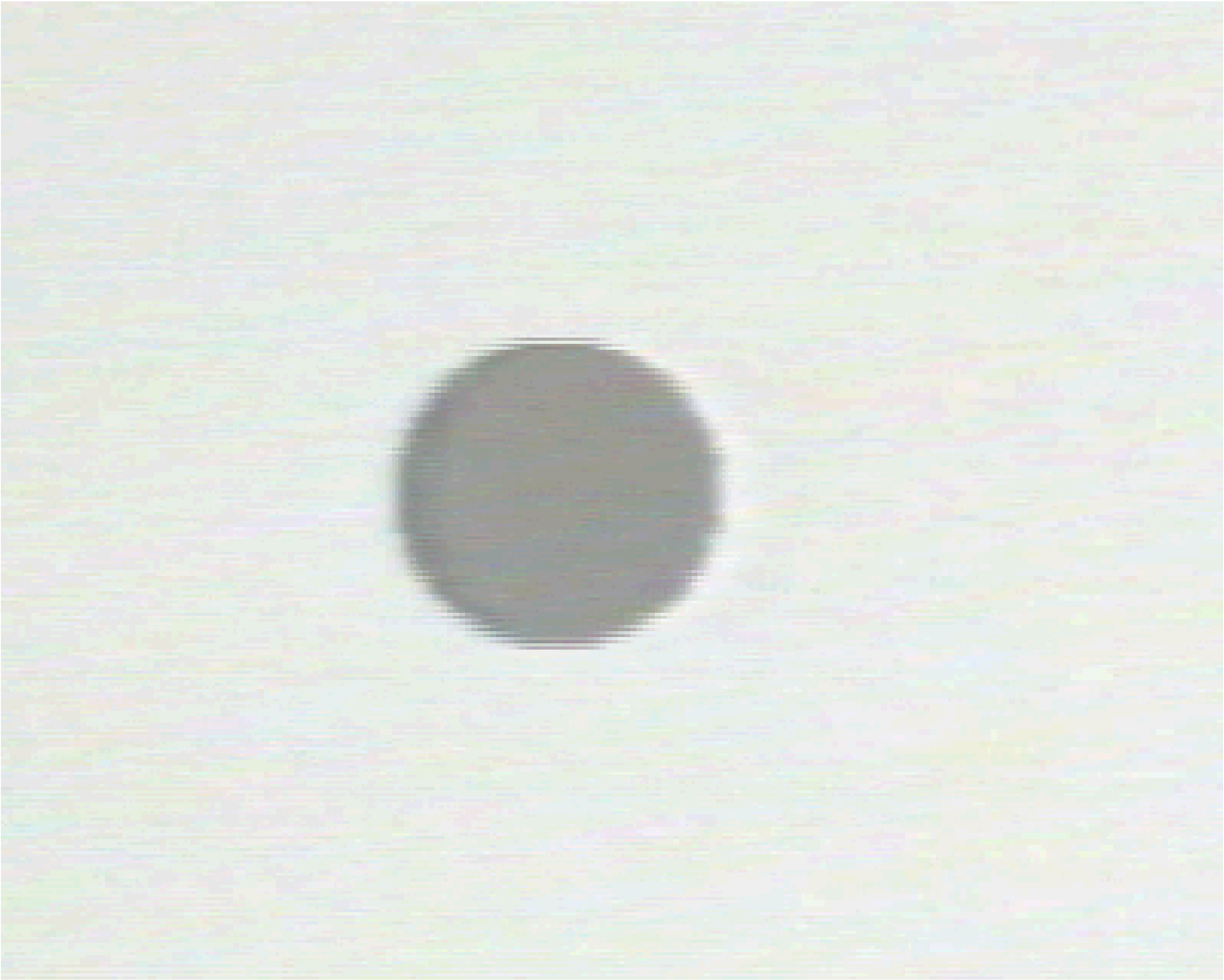
FD-TD Simulation of Scattering by Cylinder

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



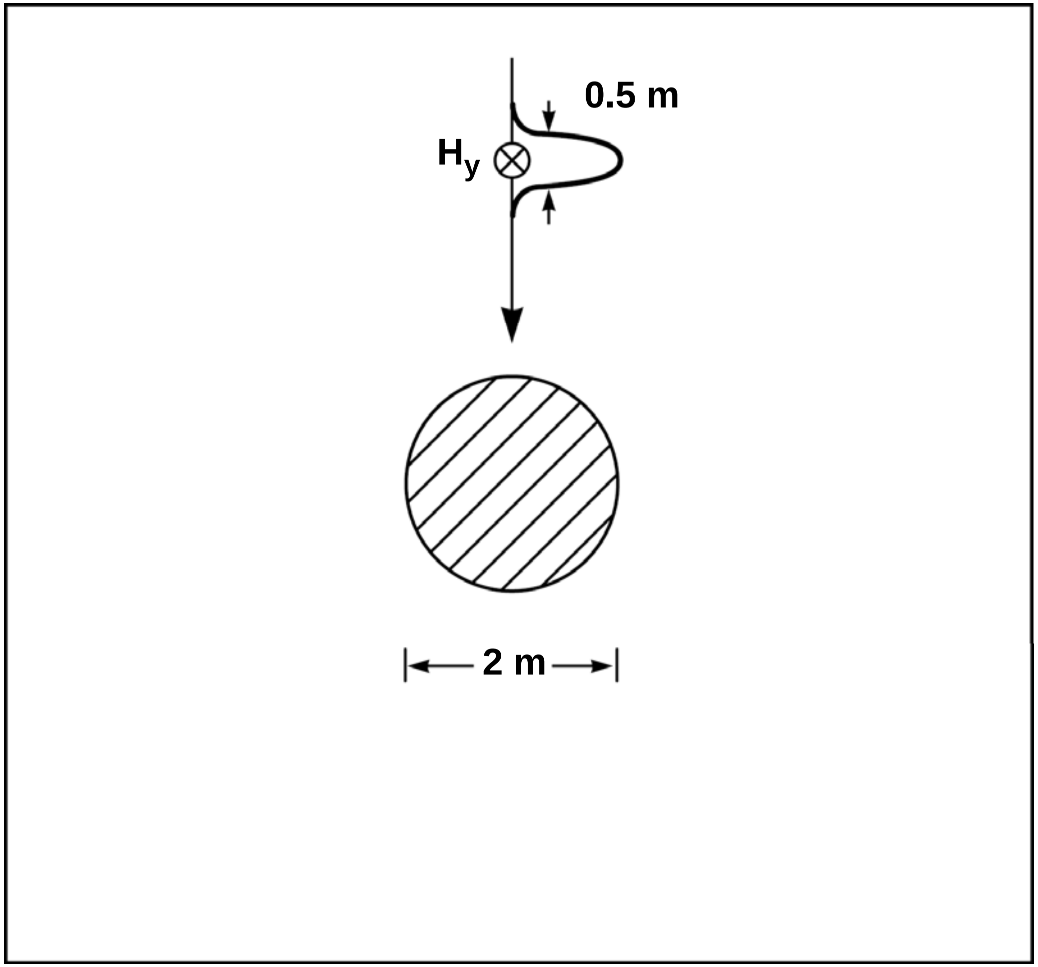


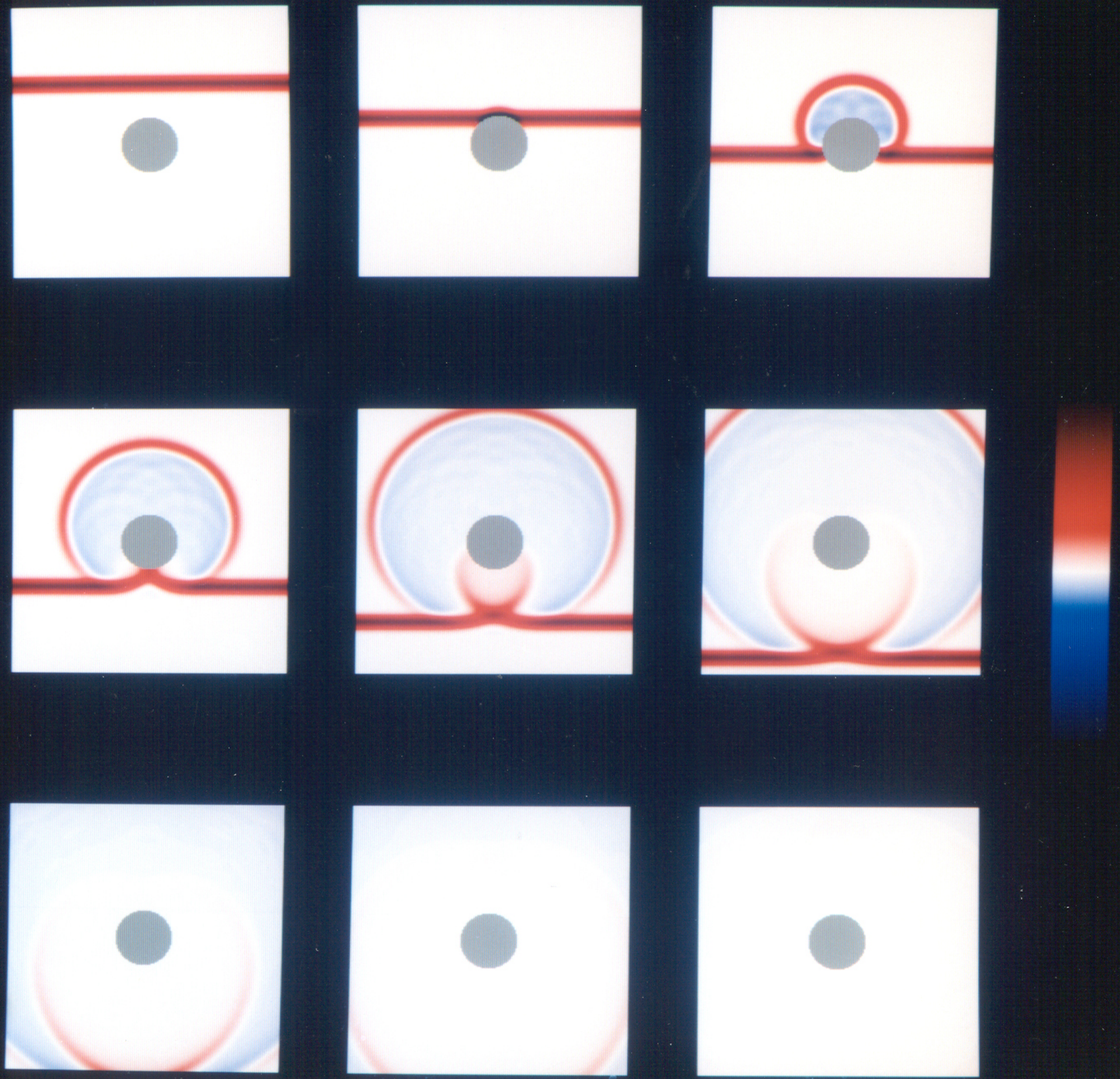
FD-TD Simulation of Scattering by Cylinder



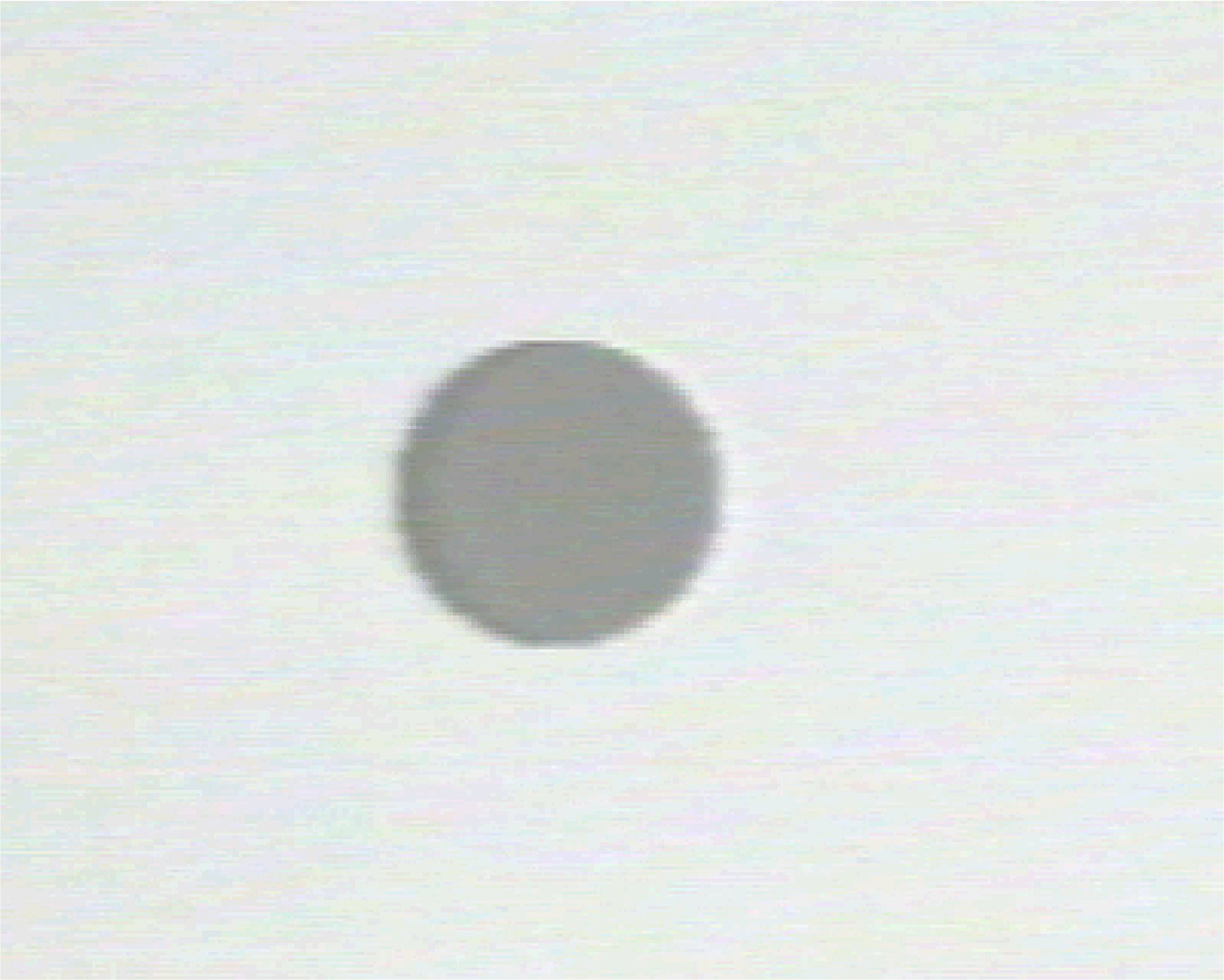
FD-TD Simulation of Scattering by Cylinder

- Gaussian pulse plane wave incidence
- H-field polarization (H_y plotted)
- Phenomena: creeping wave



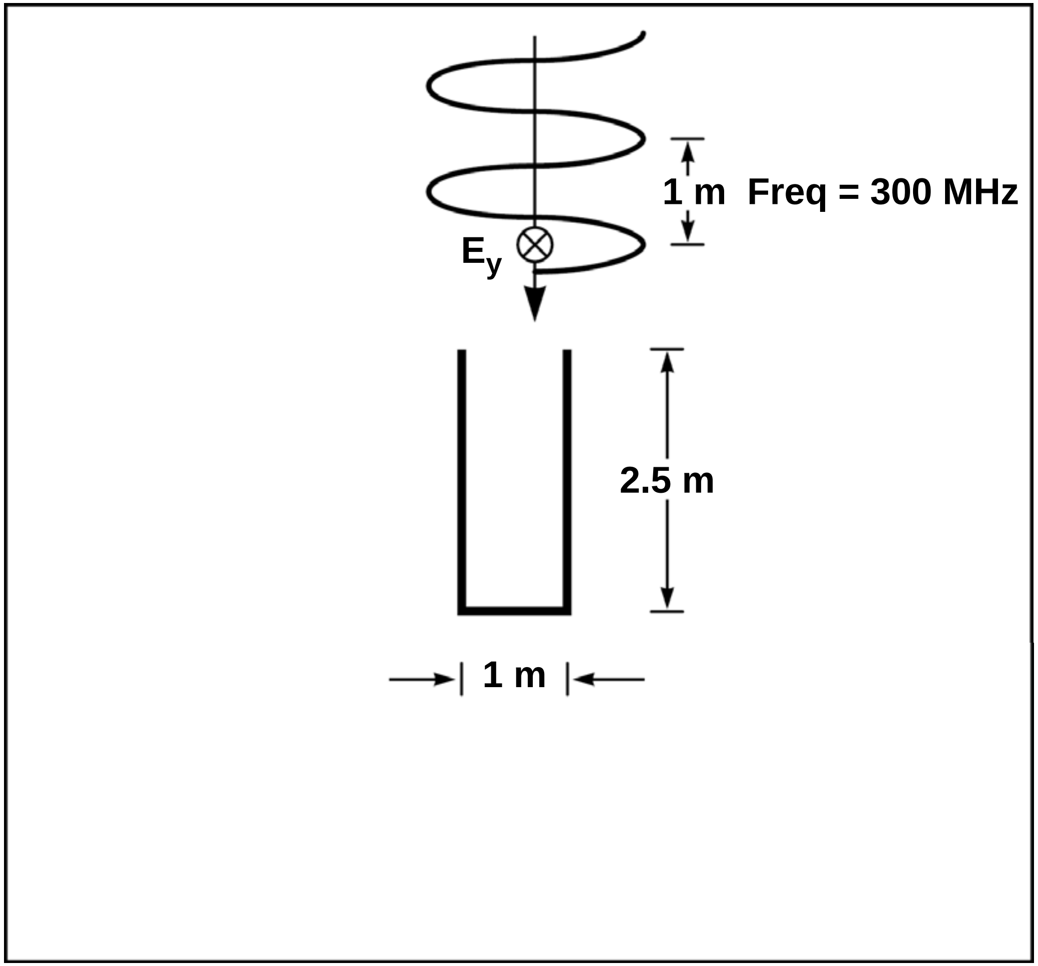


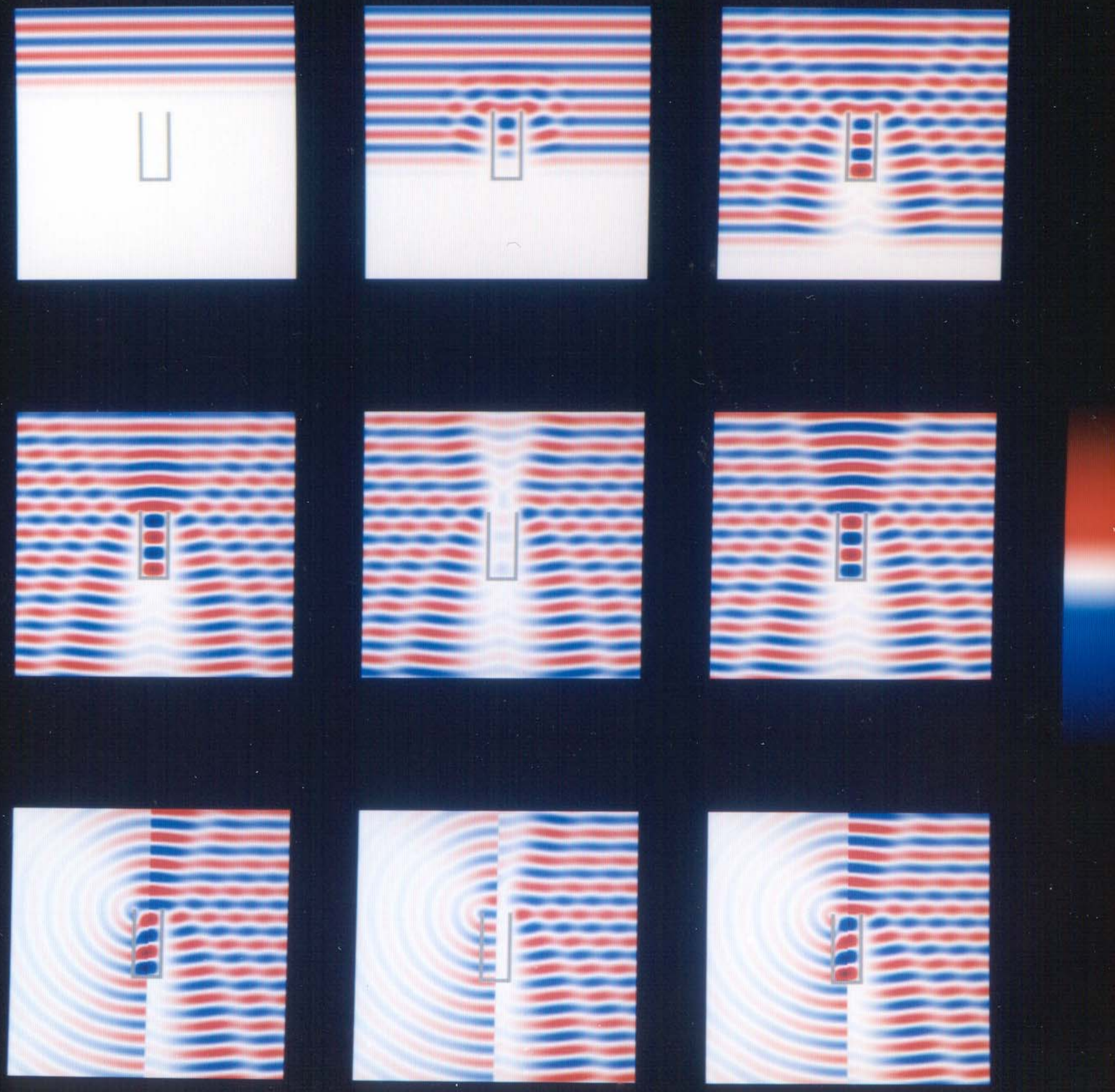
FD-TD Simulation of Scattering by Cylinder



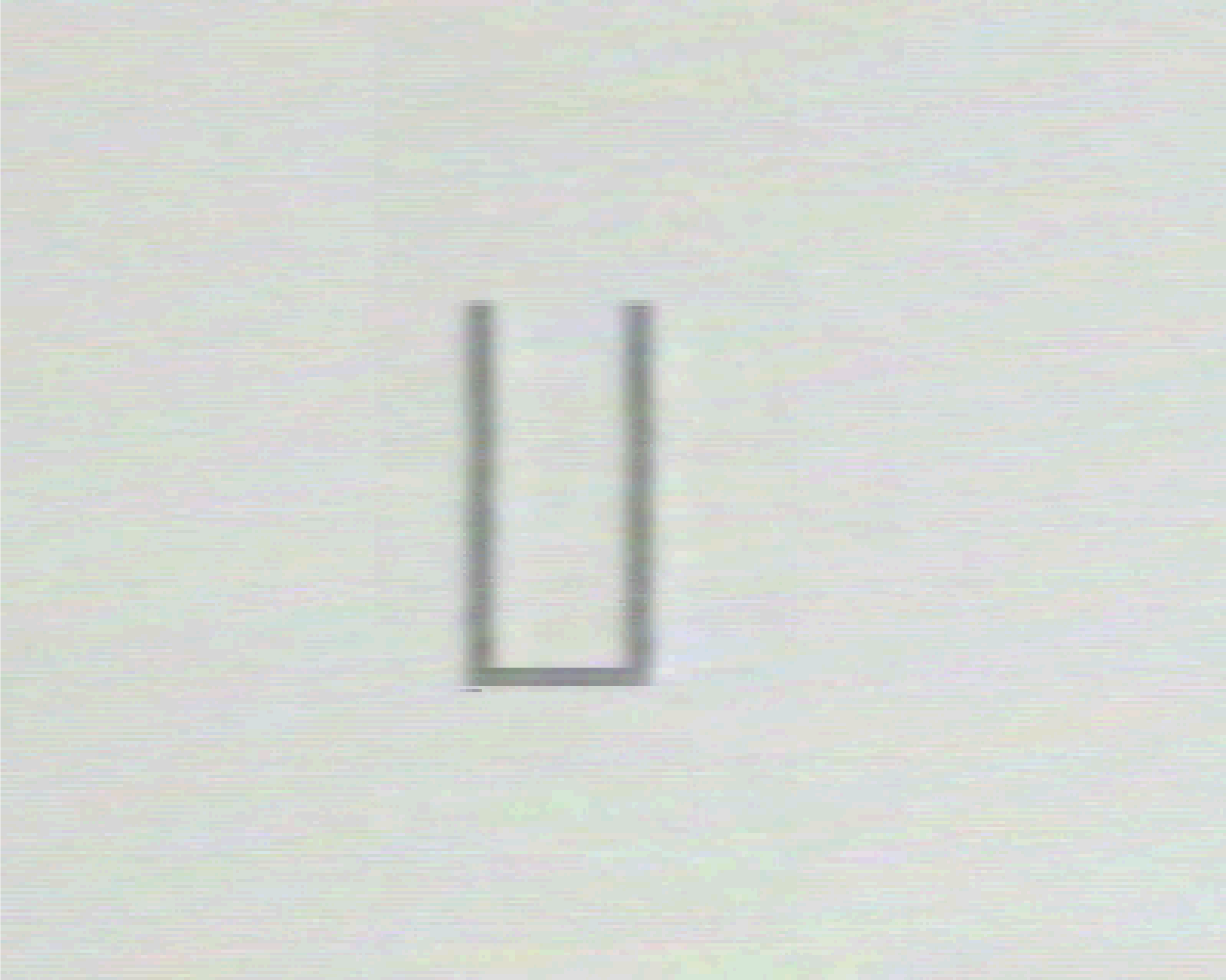
FD-TD Simulation of Scattering by Cavity

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





FD-TD Simulation of Scattering by Cavity



Outline

- **What are typical levels of radar cross section?**
  - **On what do these depend?**
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  - **Measurement**
  - **Prediction**

Techniques for RCS Analysis

FULL SCALE MEASUREMENTS

RCS PREDICTION

SCALED MODEL MEASUREMENTS

Full Scale Measurements

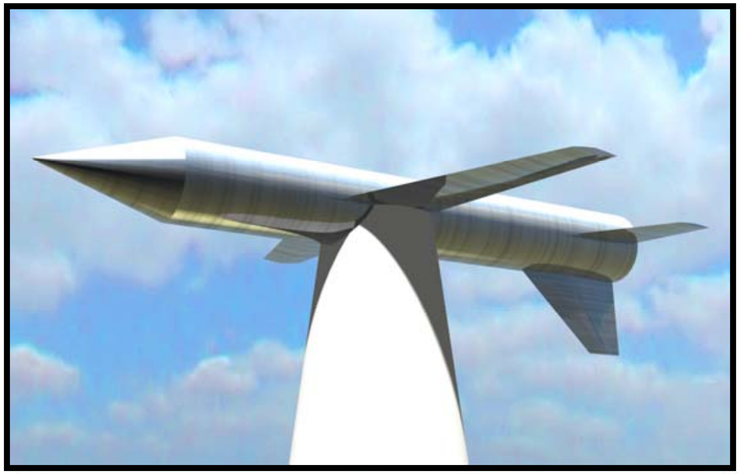
Target on support

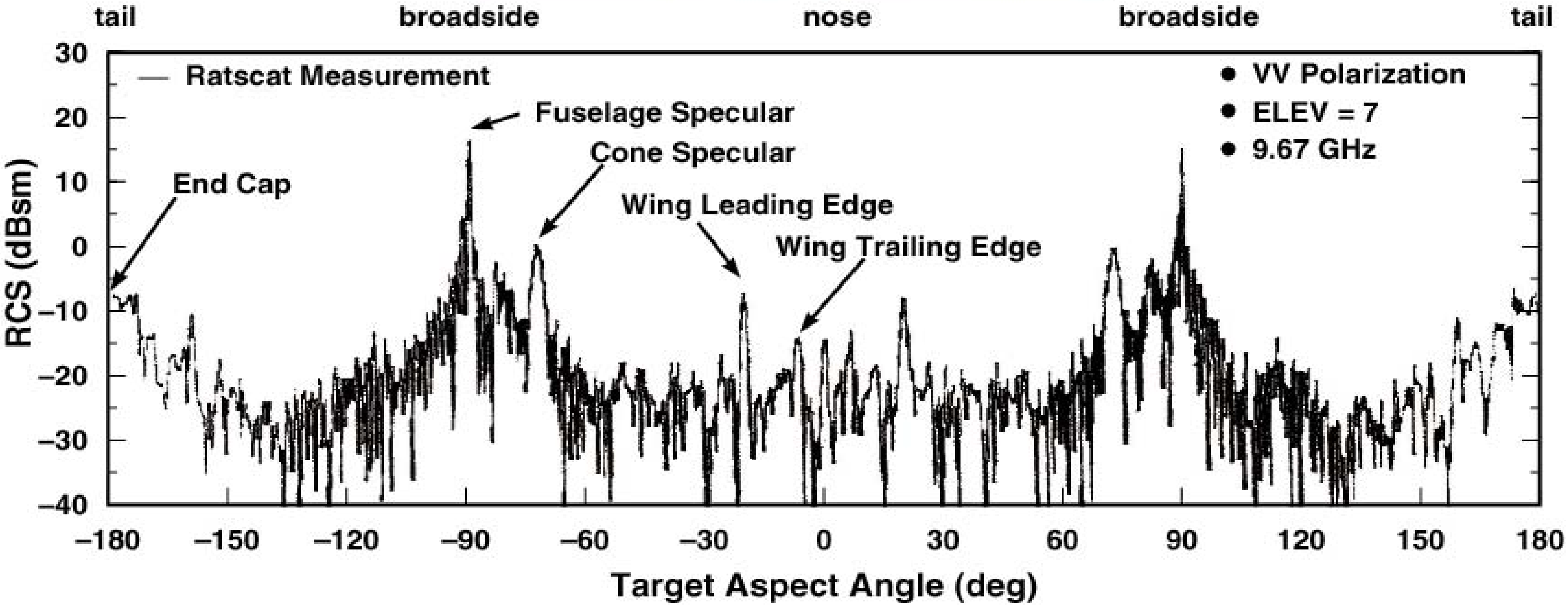
- **Foam column mounting**
  - **Dielectric properties of styrofoam close to those of free space**

- **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

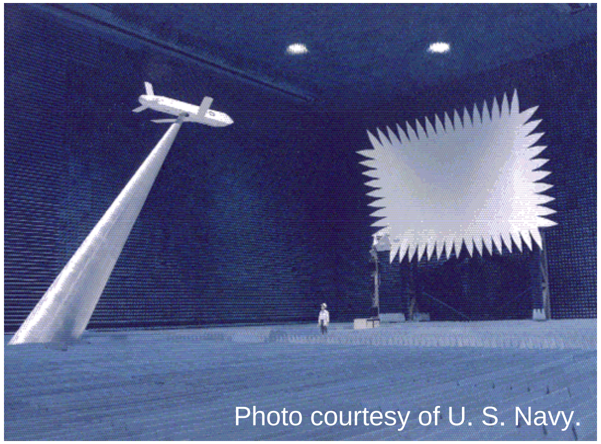
Johnson Generic Aircraft Model (JGAM)

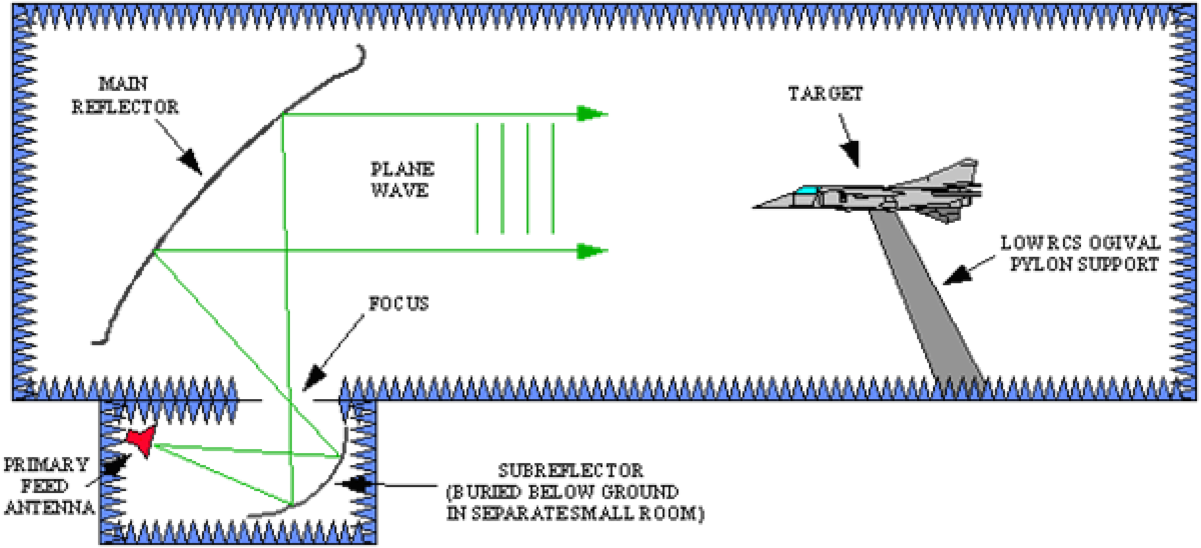




Compact Range RCS Measurement

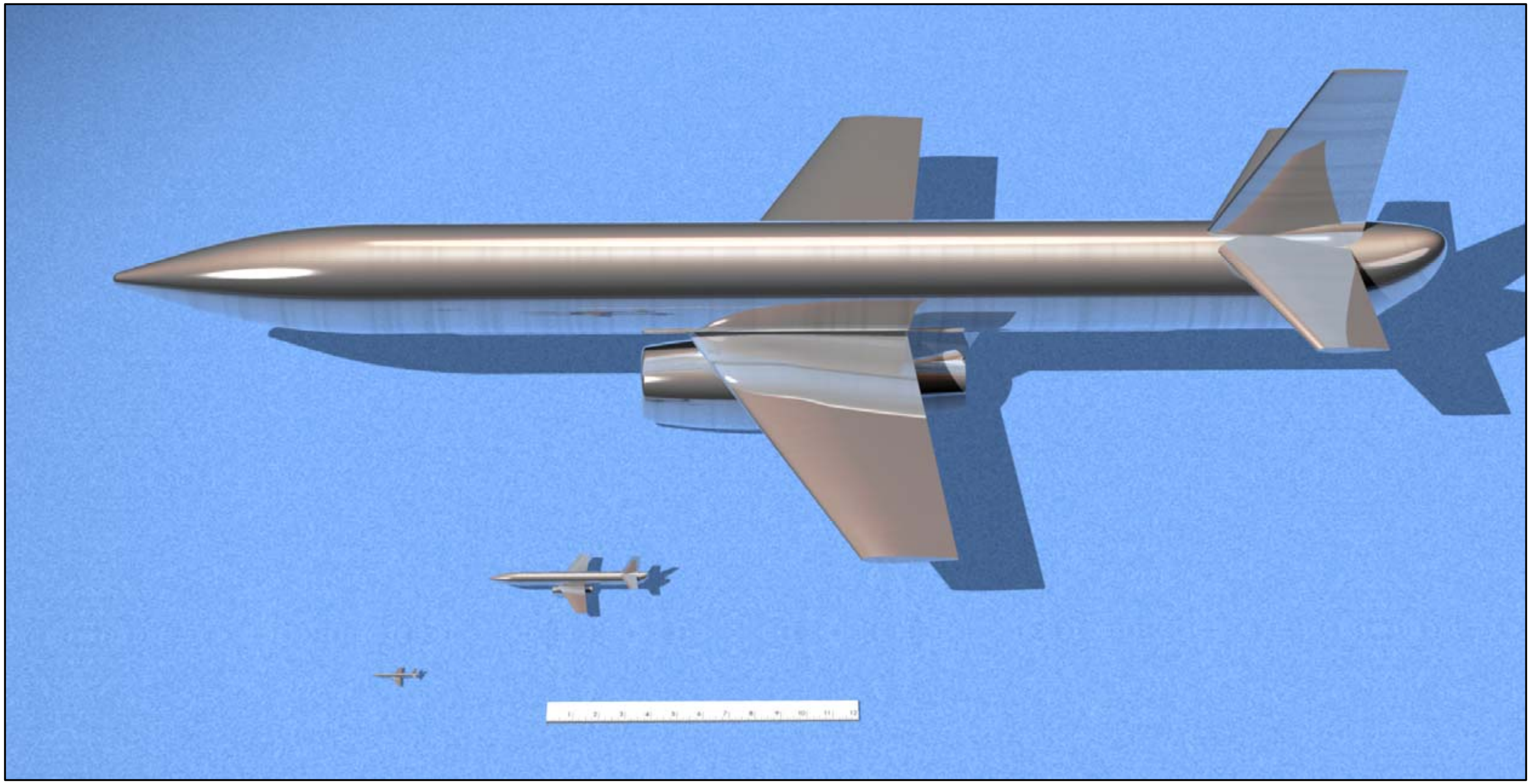
- **Radar Reflectivity Laboratory (Pt. Mugu) / AFRL Compact Range (WPAFB)**

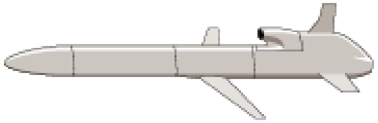


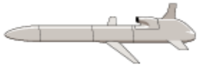


Scale Model Measurement

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



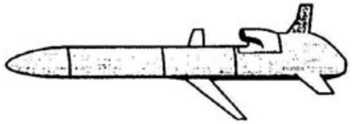


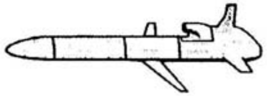


Full Scale → **Scale Factor** → **Subscale**

Full Scale	Scale Factor	Subscale
Measure at frequency f	S (Reduced Size)	Measure at frequency S x F

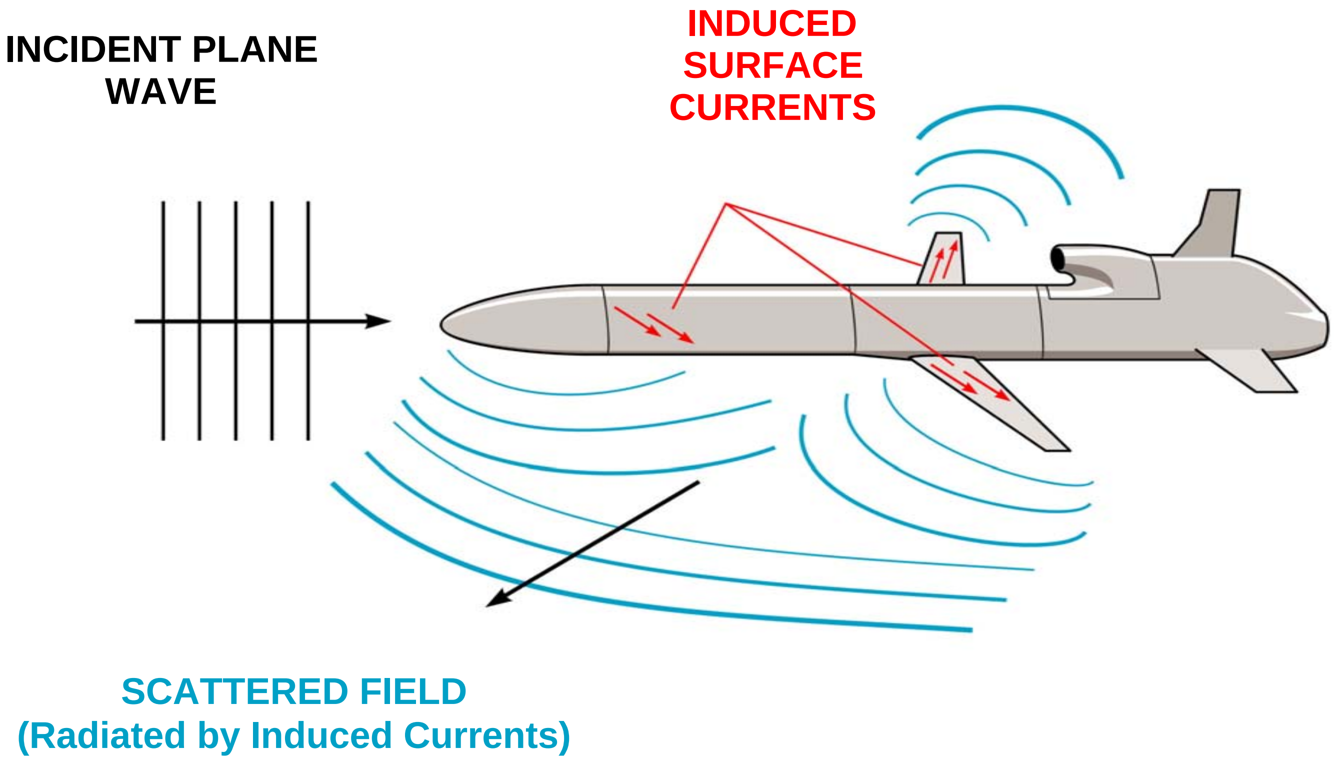
Scaling of Targets for RCS Measurements





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	$\varepsilon' = \varepsilon$
PERMEABILITY	μ	$\mu' = \mu$
RCS	σ	$\sigma' = \sigma/S^2$

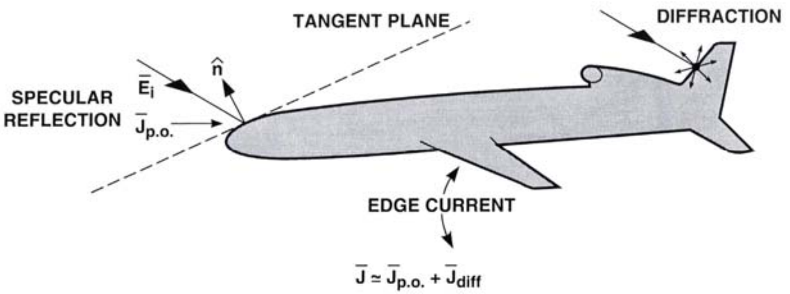
Electromagnetic Scattering



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

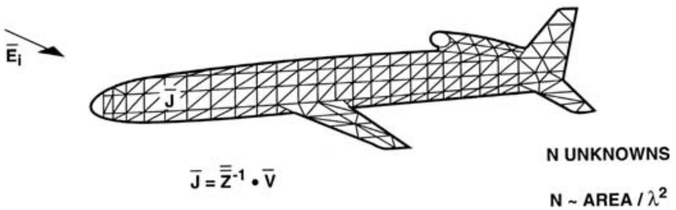
RCS Prediction Approaches

- **High frequency approximations**
  - Physical theory of diffraction



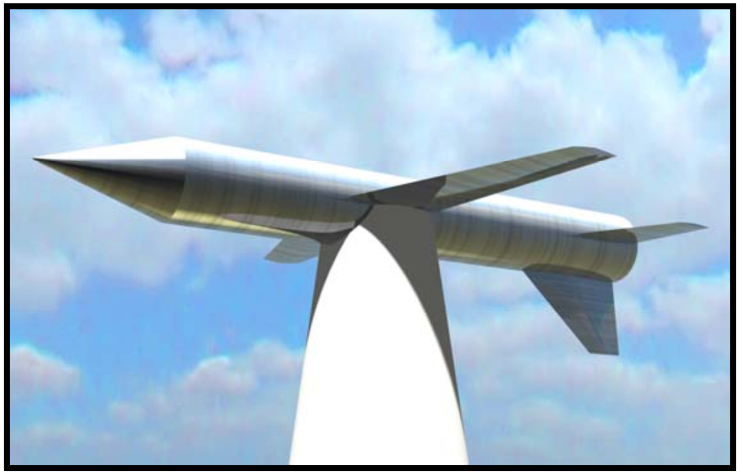
- **Advantages**
  - Reduced computational requirements
  - Arbitrary, complex geometries
- **Disadvantages**
  - Neglects some scattering
  - Applicable only to large, smooth geometries
- **Codes**
  - Xpatch

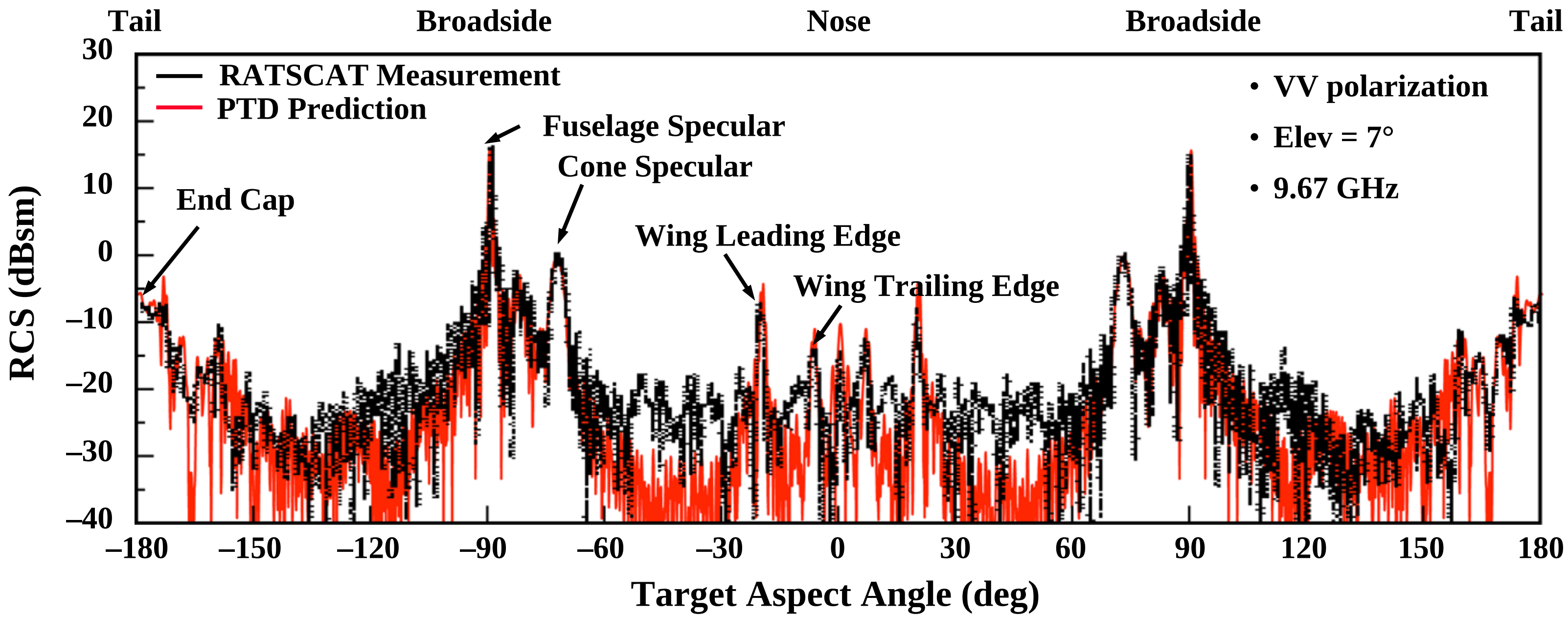
- **Exact numerical approaches**
  - Method of Moments



- **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	No issues	No issues	No issues	Significant Issues
	Surface Details	No issues	No issues	Significant Issues	No issues
	Inlet/ Exhaust	No issues	No issues	Some Issues	Significant Issues
	Materials	No issues	Some Issues	Some Issues	No issues
	Antennas	No issues	No issues / Some Issues	Significant Issues	Some Issues
Cost		Significant Issues	Some Issues / Significant Issues	Some Issues	Some Issues

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