Complex Targets
(Chapter 6)

EC4630 Radar and Laser Cross Section

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What Makes a Target Complex?

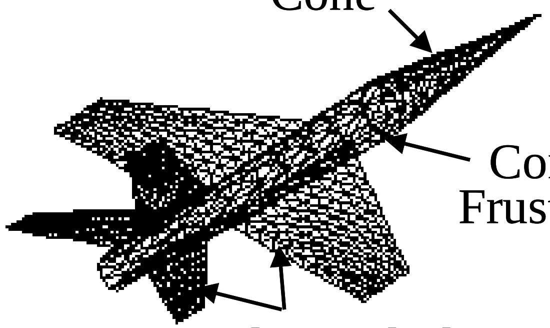
- Geometrical shape
  - Important targets are not simple plates, cones, spheres, etc.
  - The <u>geometrical components method</u> can be used with combinations of simple shapes as a first cut approximation
- Various materials
  - Inhomogeneous materials (μ, ε, σ depend on position)
  - Joins between different materials (= boundary conditions)
  - Interrupted current flow on surfaces
- Presence of sensors, primarily antennas
  - Cutouts in surfaces
  - Antennas scatter (i.e., contributes to RCS)
- Cavities
  - Air intakes, engine outlets, stacks on ships, etc.
  - Large retro-directive RCS
- Imperfections and errors
  - Targets are not PEC, perfectly flat, exact dimensions; errors and tolerances in assembly
  - Consider error sources to be random processes

Geometrical Components Method

A complex shape can be approximated by a collection of basic geometrical primitives (cones, plates, cone frustum, spheres, parallelepipeds, etc.). Superposition of the scattered fields from N components: $\vec{E}_s(P) = \sum_{n=1}^{N} \vec{E}_{s_n}(P)$

If the scattering from each body is approximated as if it were isolated in free space then

$$\left|\vec{E}_s(P)\right|^2 = \left|\vec{E}_{s_1}(P) + \vec{E}_{s_2}(P) + \cdots + \vec{E}_{s_N}(P)\right|^2$$



<u>If only one term dominates at any angle</u> (i.e., the terms are very directive), then the cross products can be neglected

$$\left|\vec{E}_s(P)\right|^2 \approx \left|\vec{E}_{s_1}(P)\right|^2 + \left|\vec{E}_{s_2}(P)\right|^2 + \cdots + \left|\vec{E}_{s_N}(P)\right|^2$$

and the RCS becomes

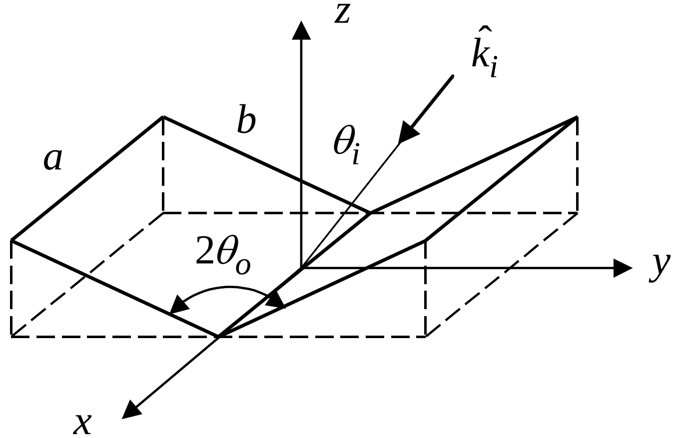
$$\sigma \approx \frac{4\pi R^2}{\left|\vec{E}_i(P)\right|^2} \left|\vec{E}_s(P)\right|^2 = \sigma_1 + \sigma_2 + \cdots + \sigma_N$$

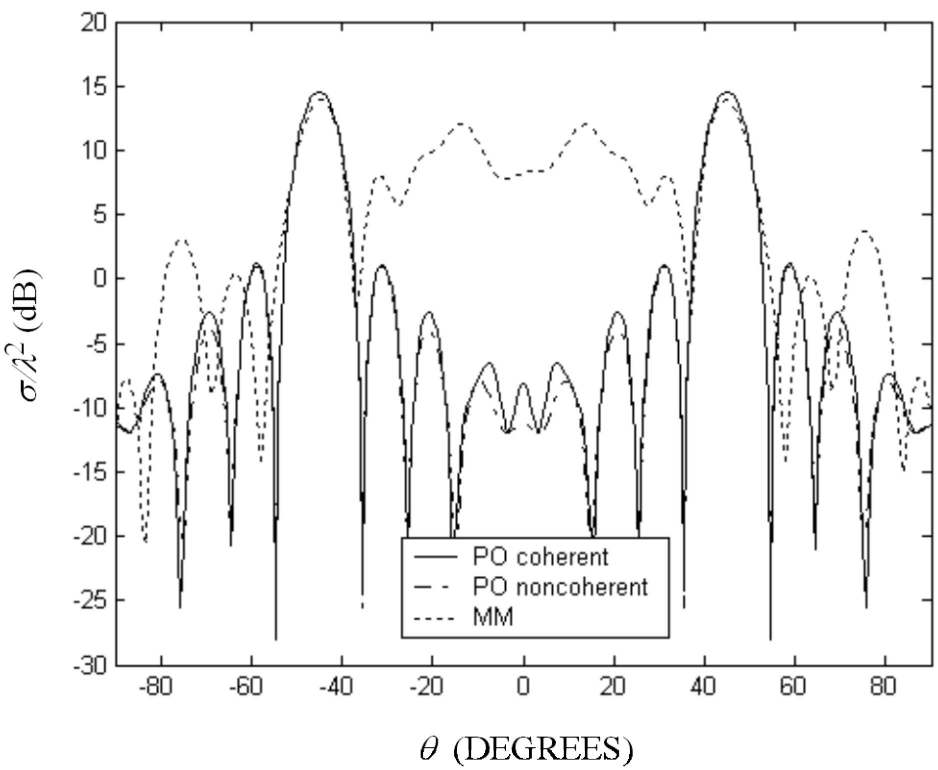
Interactions Using Geometrical Components

Interactions between items in a geometrical components model can be very important. They include:

- Multiple reflections
- Edge diffraction
- Shadowing

Simple example: 2 plates forming a corner reflector, $2\theta_o = 90^\circ$



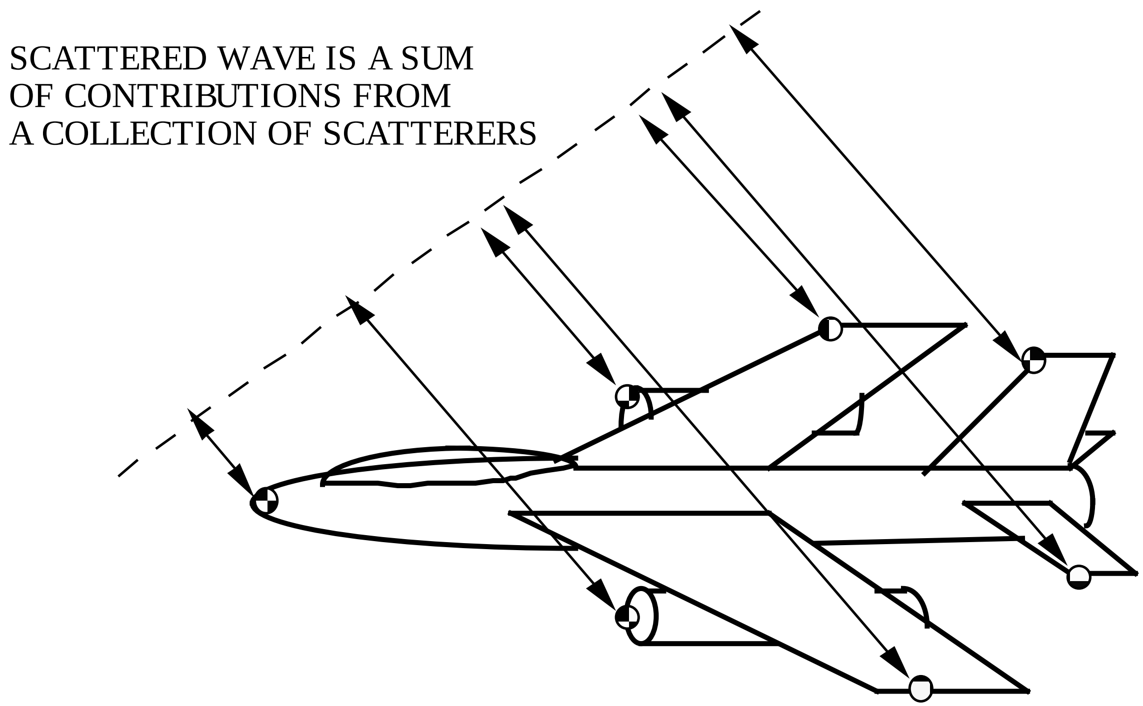


- Without including multiple reflections a large error in RCS results near 0 degrees

Approximate Scattering Models

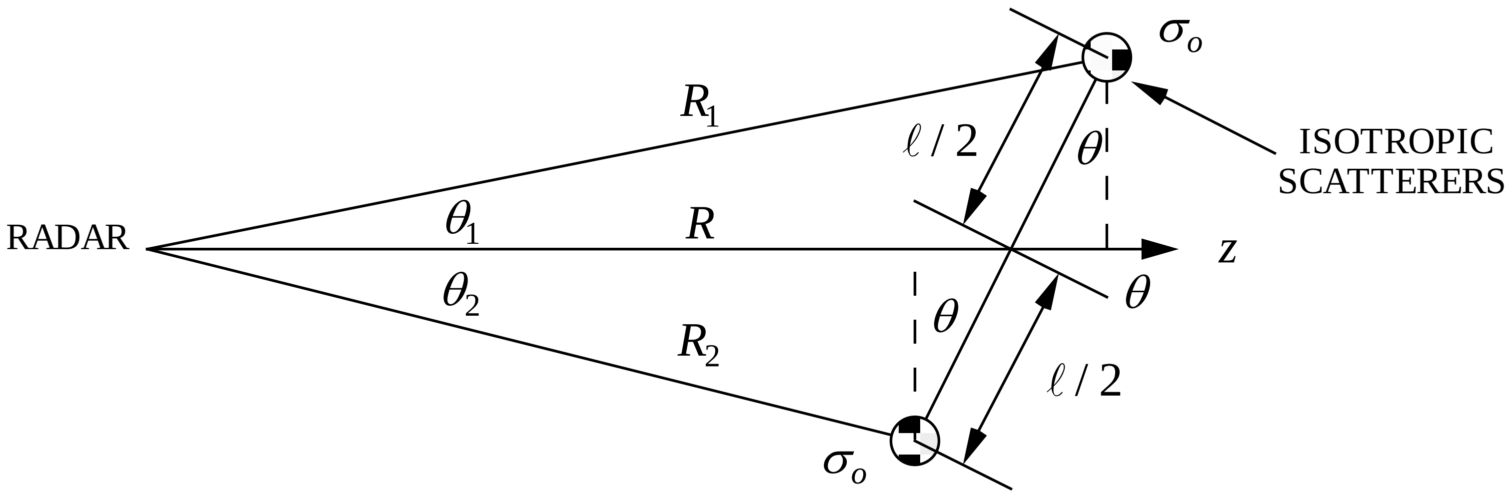
An array of scatterers is used to represent the gross behavior of complex targets. Scatterer locations correspond to physical sources of scattering. Complex weights are applied to account for the strength and phasing. The weights can be frequency and spatially dependent. Similar to the geometrical components method, the total RCS for *N* scatterers is

$$\left|\vec{E}_s(P)\right|^2 = \left|\vec{E}_{s_1}(P) + \vec{E}_{s_2}(P) + \cdots + \vec{E}_{s_N}(P)\right|^2$$



Array of Isotropic Scatterers (1)

Consider the RCS obtained from two isotropic scatterers (approximated by spheres).



Law of cosines:

$$R_1 = \sqrt{R^2 + (\ell/2)^2 - 2R(\ell/2)\cos(\theta + \pi/2)} = R\sqrt{1 + (\ell/2R)^2 + 2(\ell/2R)\sin\theta}$$

$$R_2 = \sqrt{R^2 + (\ell/2)^2 - 2R(\ell/2)\cos(\theta - \pi/2)} = R\sqrt{1 + (\ell/2R)^2 - 2(\ell/2R)\sin\theta}$$

Let $\alpha = \ell \sin\theta / R$ and note that

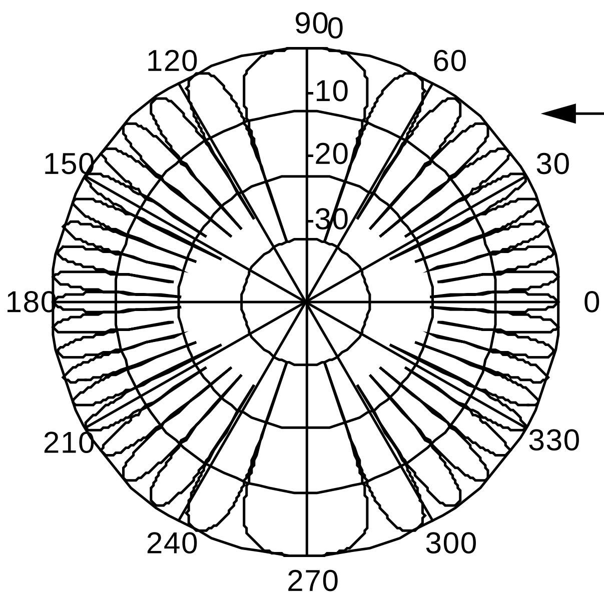
$$(1 \pm \alpha)^{1/2} = 1 \pm \frac{1}{2}\alpha \mp \underbrace{\frac{3}{8}\alpha^2 \pm \cdots}_{\text{NEGLECT SINCE } \alpha \ll 1}$$

Array of Isotropic Scatterers (2)

Keeping the first two terms in each case leads to the approximate expressions $R_1 \approx R + (\ell/2)\sin\theta$ and $R_2 \approx R - (\ell/2)\sin\theta$. Total effective RCS of the two spheres is:

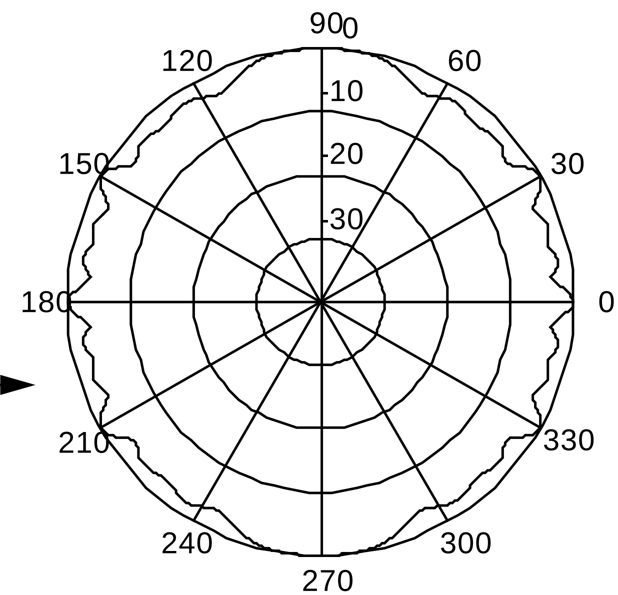
$$\sigma_{\text{eff}} = 4\pi R^2 \left|E_s\right|^2 = 4\pi R^2 \left| E_o \left(e^{-j2k\frac{\ell}{2}\sin\theta} + e^{j2k\frac{\ell}{2}\sin\theta} \right) \right|^2 = 4\sigma_o \cos^2(k\ell\sin\theta)$$

where $k = 2\pi/\lambda$ and $\left|E_o\right| = \sqrt{\sigma_o / 4\pi R^2} = \left| A e^{-jkR} / R \right|$. A is the scattering amplitude of the element. This can easily be extended to N spheres of various amplitudes.



NORMALIZED PLOT OF $\sigma_{\text{eff}} / \sigma_{\text{o}}$ FOR 2 SPHERES SPACED 10λ $\sigma_{\text{o}n} = (1,1)$

NORMALIZED PLOT OF $\sigma_{\text{eff}} / \sigma_{\text{o}}$ FOR 7 SPHERES SPACED 2λ $\sigma_{\text{o}n} = (1,1,1,10,1,1,1)$



Swerling Target Types

The target return appears to vary with time due to sources other than a change in range:

1. meteorological conditions and path variations
2. radar system instabilities (platform motion and equipment instabilities)
3. target aspect changes for targets in the optical region (many sidelobes)

For systems analysis purposes we only need to know the "gross" behavior of a target, not the detailed physics behind the scattering. Let the σ be a random variable with a probability density function (PDF) that depends on the factors above. Two PDFs are commonly used:

1. $p(\sigma) = \frac{1}{\bar{\sigma}} e^{-\sigma/\bar{\sigma}}$ (this is a negative exponential PDF)

These are Rayleigh targets which consist of many independent scattering elements of which no single one (or few) predominate.

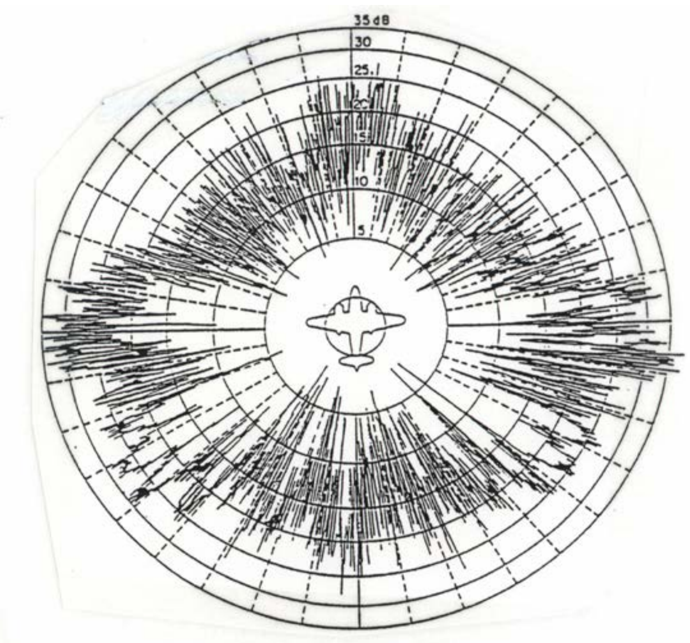
2. $p(\sigma) = \frac{4\sigma}{\bar{\sigma}^2} e^{-2\sigma/\bar{\sigma}}$

These targets have one main scattering element that dominates, together with smaller independent scattering sources.

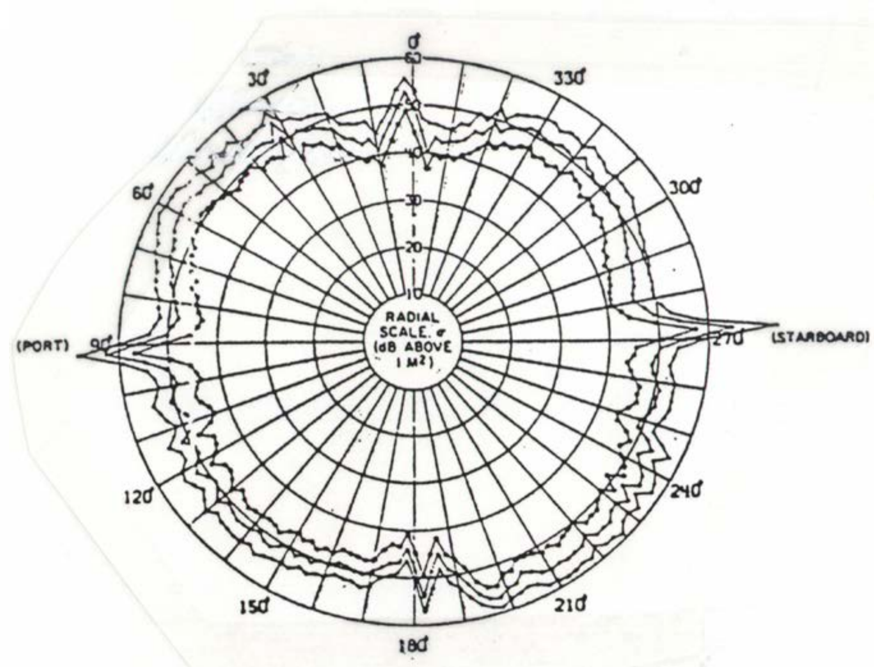
Swerling Types

Using PDFs #1 and #2 we define four Swerling target types:

1. Type I: PDF #1 with slow fluctuations (scan-to-scan)
2. Type II: PDF #1 with rapid fluctuations (pulse-to-pulse)
3. Type III: PDF #2 with slow fluctuations (scan-to-scan)
4. Type IV: PDF #2 with rapid fluctuations (pulse-to-pulse)



Large bomber (PDF #1)



Large ship (PDF #2)