Nadav Levanon, Tel-Aviv University

CROSS SECTION OF RADAR TARGETS

σ = The area of a virtual target which reflects back isotropically, that would have caused the same return as the actual target.

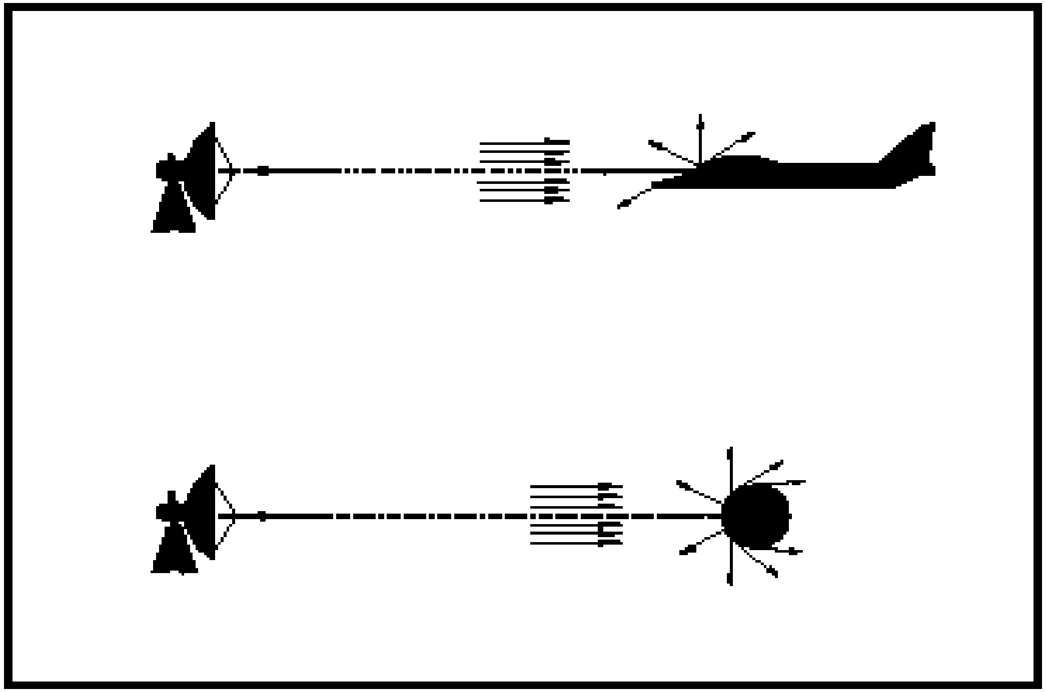

Figure 1. Concept of Radar Cross Section

Dimension of σ is m^2 (i.e., area)

DETERMINISTIC TARGETS

- Sphere, plane, corner reflector, antenna
- Complex target (multiple scatterers) when the range and angular resolutions separates between the target's elements (and there are no other targets)

STATISTICAL TARGETS

- Multiple scatterers (when the range and angular resolutions do not separate between the target's elements)
- Fluctuating targets (movement changes aspect angle)
- Distributions, Swerling models

Radar Calibration Spheres shown with optional polished finish

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* Standard Finish is 63 micrometers; Material is Aluminum

Sizes of Metal Balls

Sizes	Sphericity
14" OD Calibration Sphere	.035
	.010
	.005
12" OD Sphere	.035
	.010
	.005
10" OD Sphere	.020
	.005
8" OD Sphere	.020
	.005
6" OD Sphere	.020
	.005

14" Aluminum Sphere

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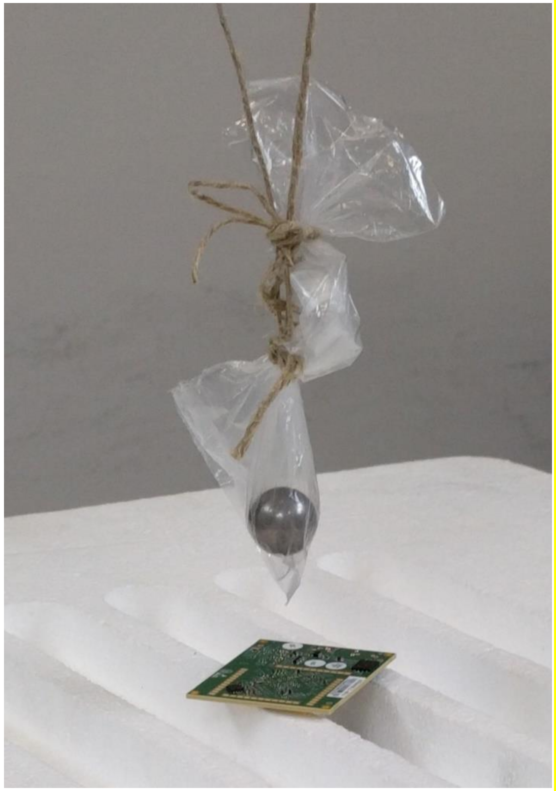


Vayyar, 4 Nov 2019

Nadav Levanon, Tel-Aviv University

RAYLEIGH REGION

$\sigma = [\pi r^2][7.11(kr)^4]$

where: $k = 2\pi/\lambda$

MIE (resonance)

$\sigma = 4\pi r^2$ at Maximum (point A)

$\sigma = 0.26\pi r^2$ at Minimum (pt B)

OPTICAL REGION

$\sigma = \pi r^2$

(Region RCS of a sphere is independent of frequency)

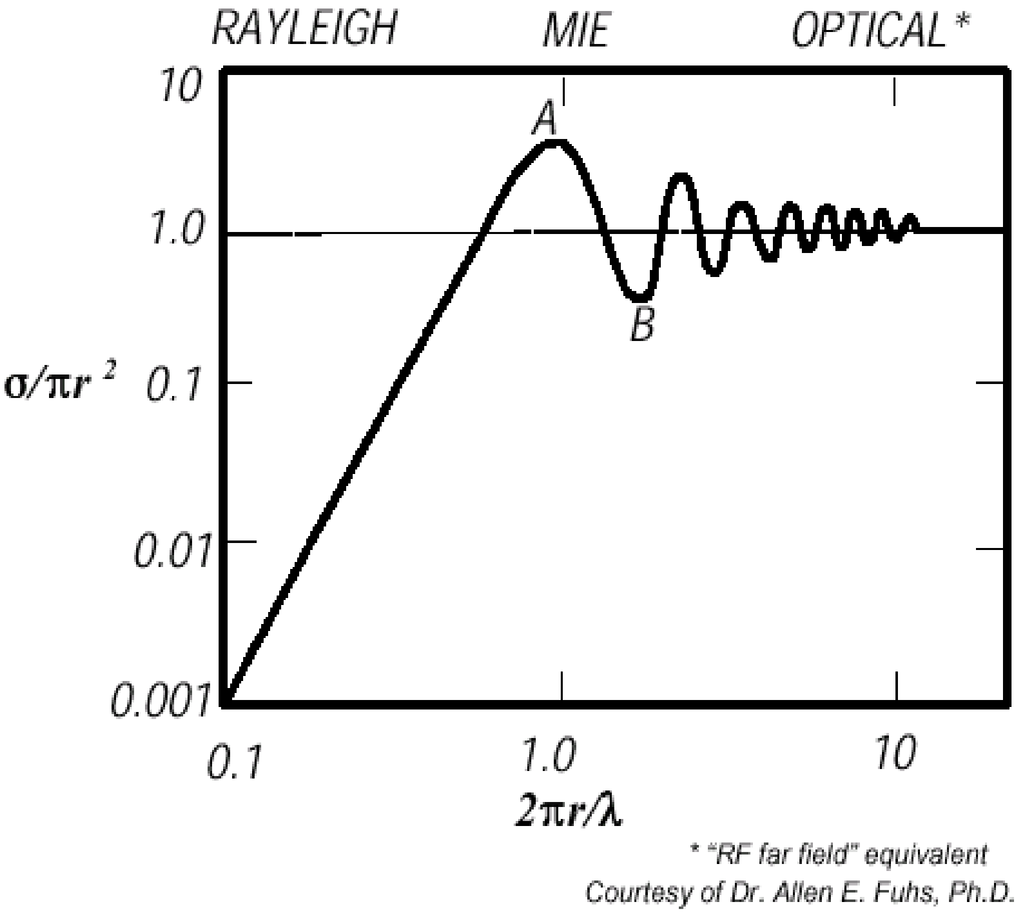
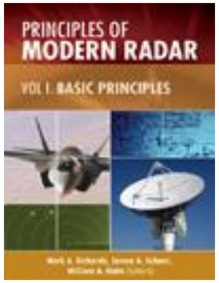
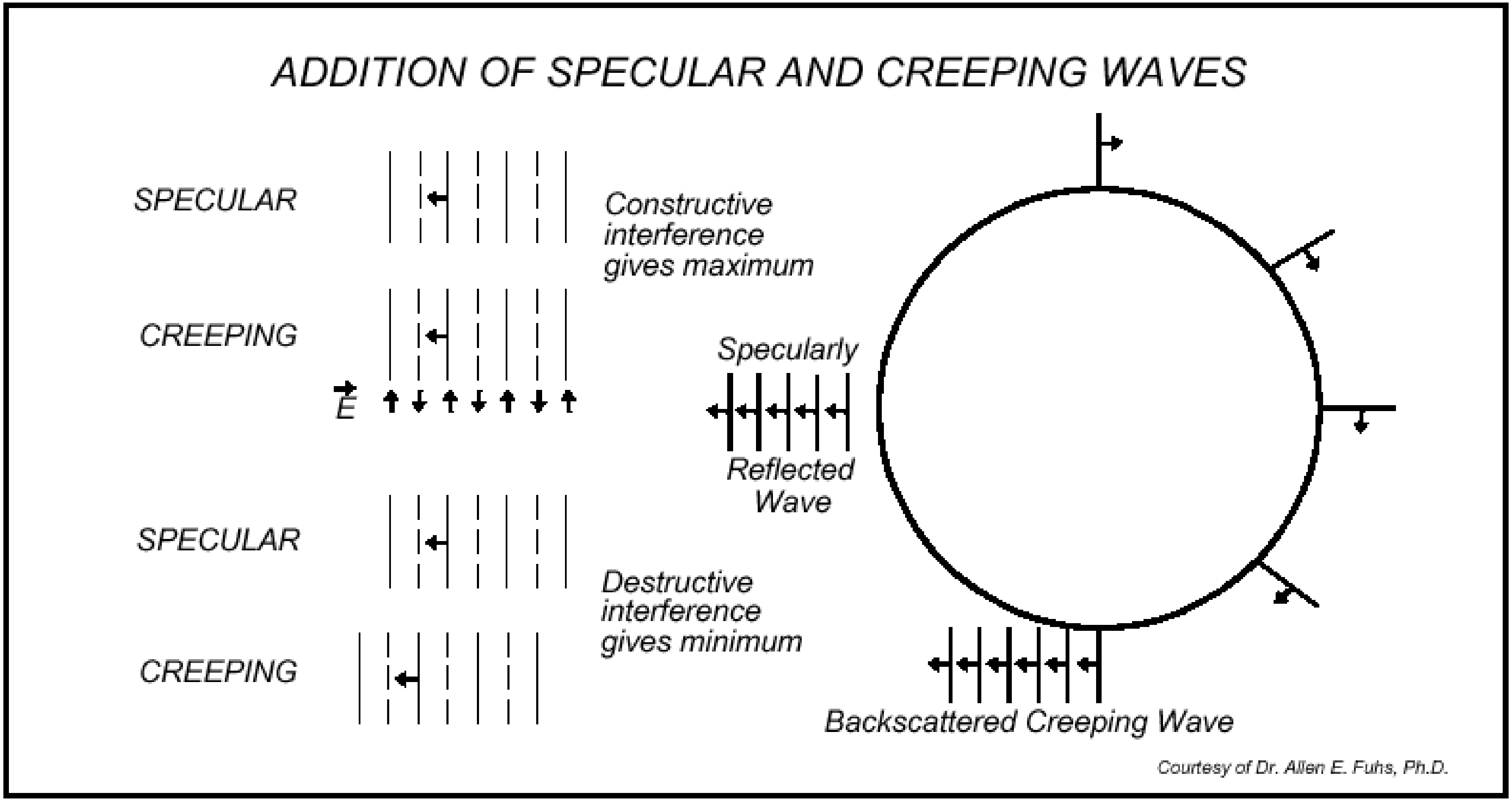
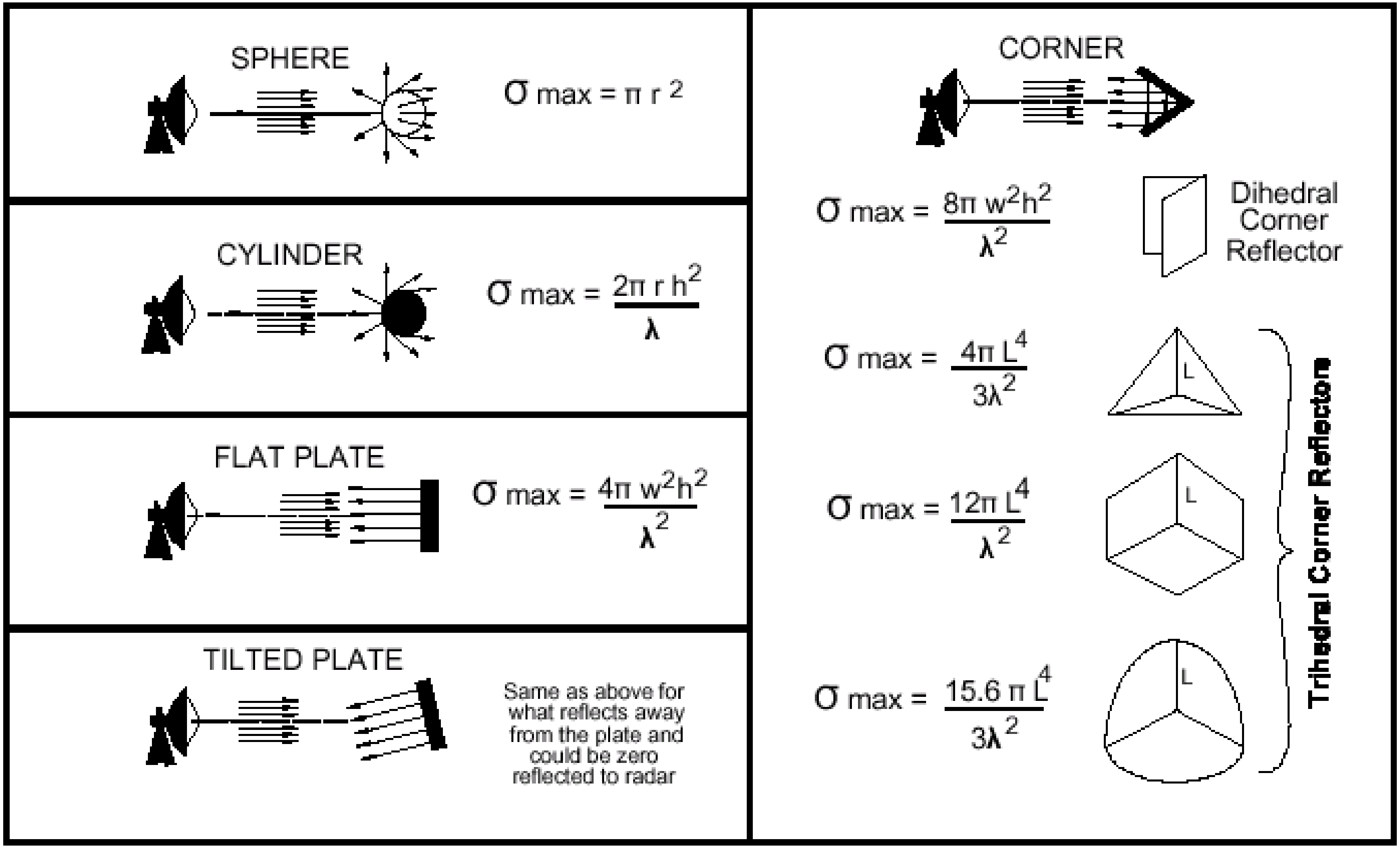


Figure 7. Radar Cross Section of a Sphere

A plot of the RCS of a conducting sphere appears <u>three</u> times in the book:
M.A. Richards: "*Principles of Modern Radar – Basic Principles* ", SciTech, 2010:
Fig. 5-5, page 174, Fig. 6-12, page 225, Fig. 7-2, page 248.




ADDITION OF SPECULAR AND CREEPING WAVES
SPECULAR
CREEPING
E
Constructive interference gives maximum
SPECULAR
CREEPING
Destructive interference gives minimum
Specularly
Reflected Wave
Backscattered Creeping Wave
Courtesy of Dr. Allen E. Fuhs, Ph.D.


SPHERE
$\sigma_{max} = \pi r^2$
CYLINDER
$\sigma_{max} = \frac{2\pi r h^2}{\lambda}$
FLAT PLATE
$\sigma_{max} = \frac{4\pi w^2 h^2}{\lambda^2}$
TILTED PLATE
Same as above for what reflects away from the plate and could be zero reflected to radar
CORNER
$\sigma_{max} = \frac{8\pi w^2 h^2}{\lambda^2}$
Dihedral Corner Reflector
$\sigma_{max} = \frac{4\pi L^4}{3\lambda^2}$
$\sigma_{max} = \frac{12\pi L^4}{\lambda^2}$
$\sigma_{max} = \frac{15.6\,\pi L^4}{3\lambda^2}$
L
Trihedral Corner Reflectors

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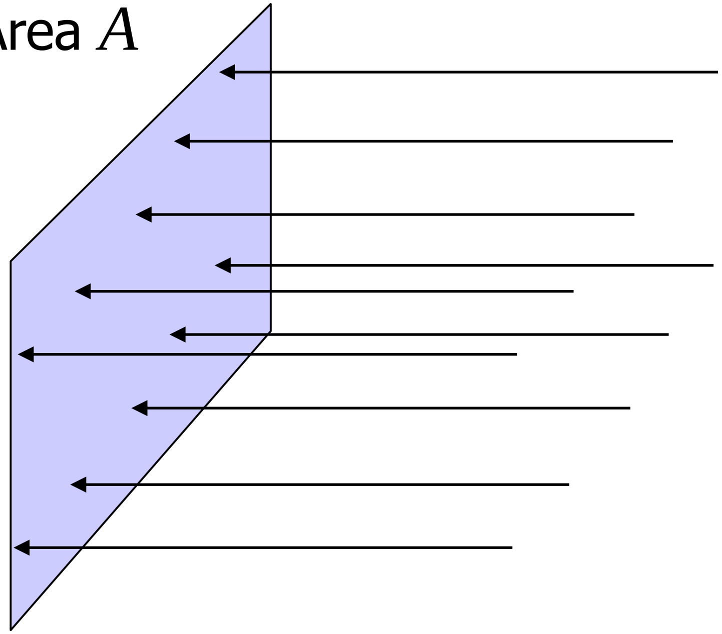
PLANAR SURFACE (FLAT PLANE)
Normal direction ($\theta = 0$)

Area A



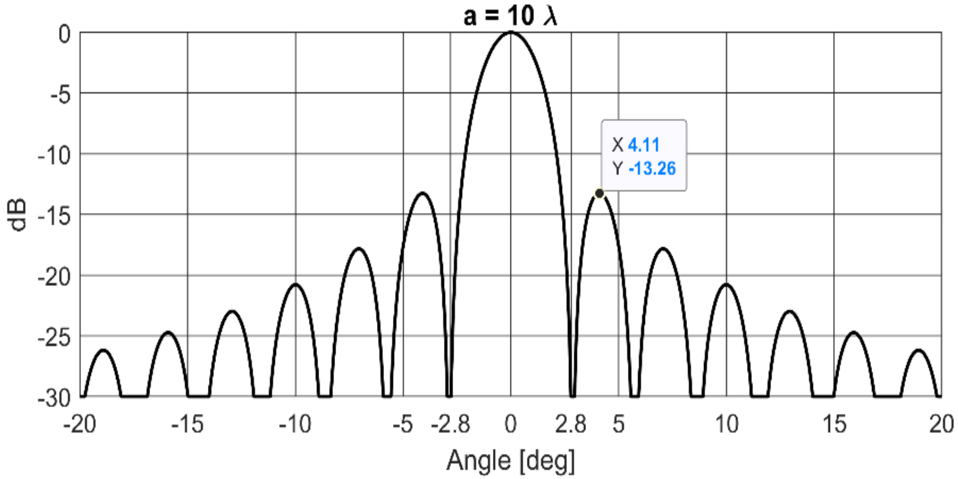
- Power flux intercepted by area A
- If the power was reflected back isotropically then $\sigma = A$
- Large, smooth surface reflects most of the power back with gain

$$G = \frac{4\pi A}{\lambda^2} \qquad \sqrt{A} >> \frac{\lambda}{2\pi} \qquad \sigma = AG = \frac{4\pi A^2}{\lambda^2}$$

For a square a x a, $\theta \neq 0$:

$$\sigma = \frac{4\pi a^4}{\lambda^2}\left[\frac{\sin\left(ka\sin\theta\right)}{ka\sin\theta}\right]^2$$

$$k = \frac{2\pi}{\lambda}$$



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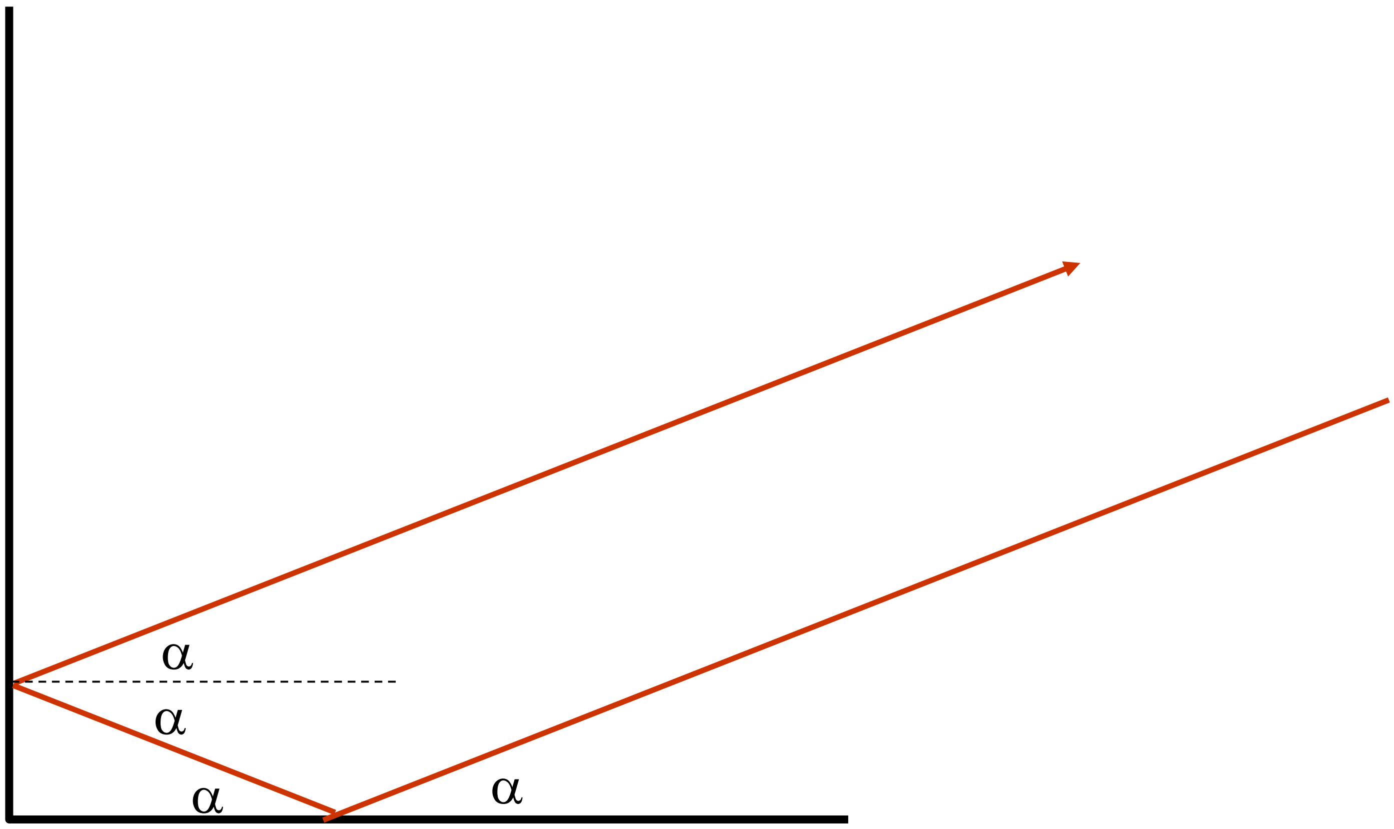
Principle of corner reflector



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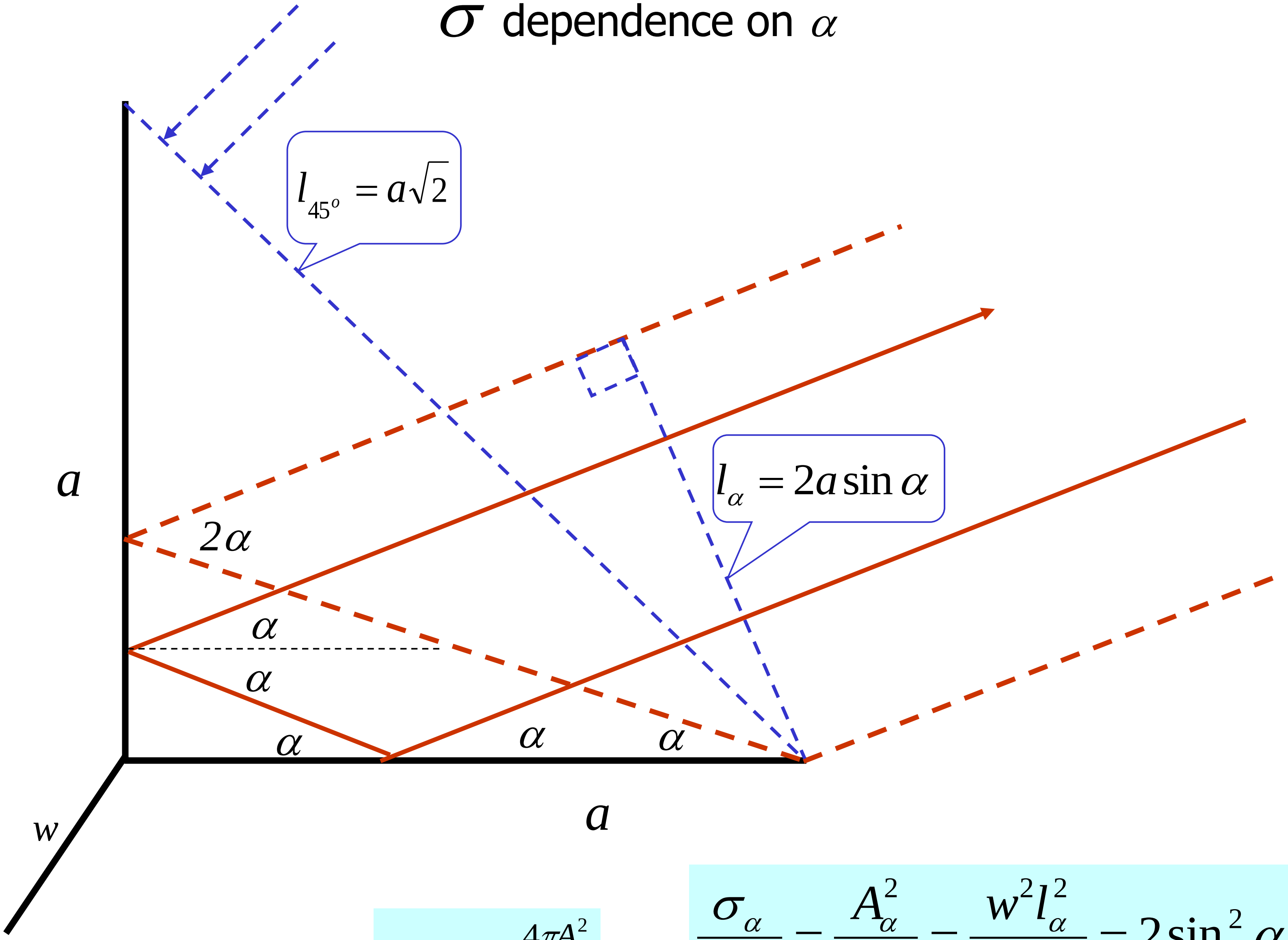
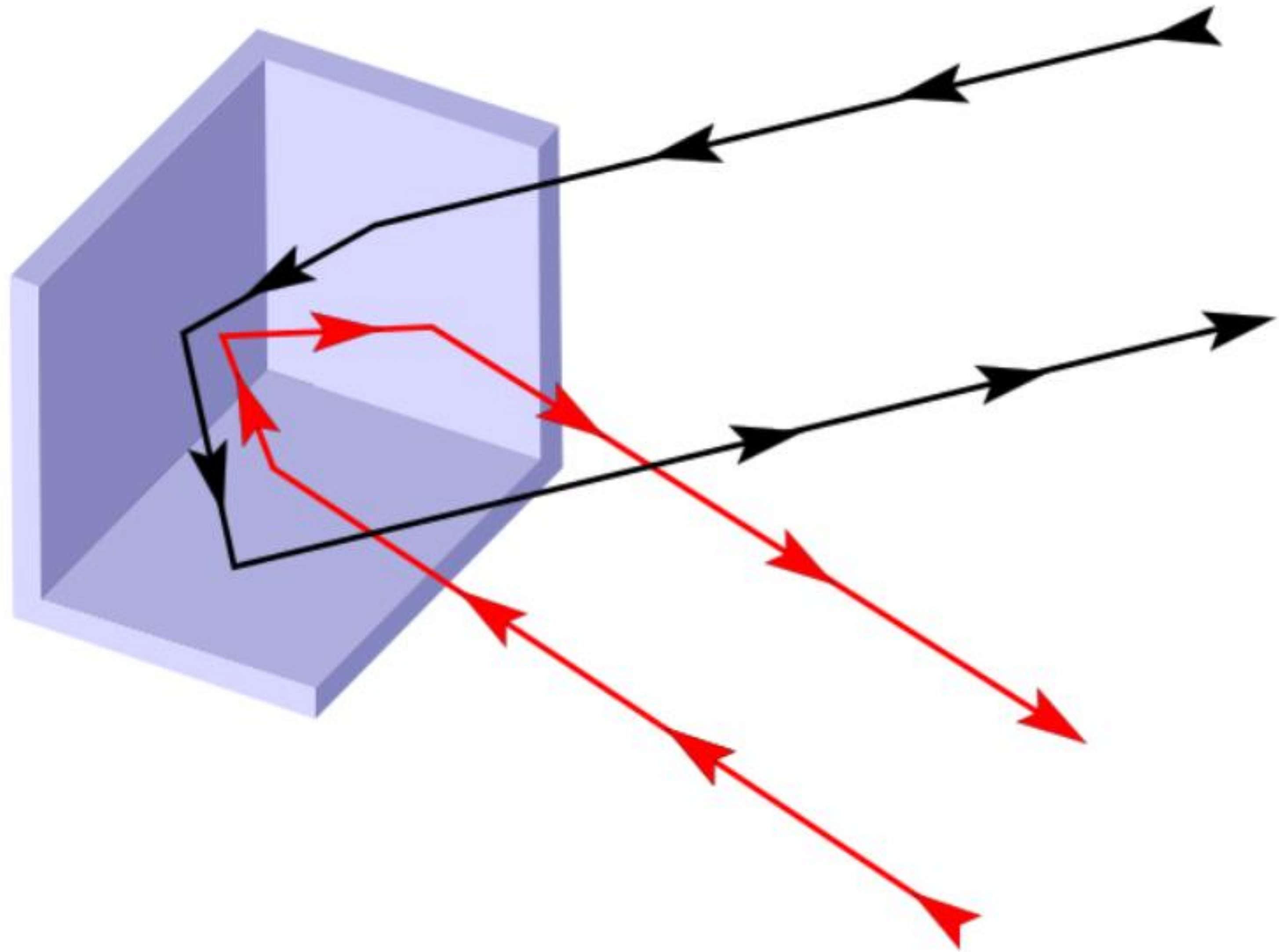
σ dependence on α



$$\sigma = AG = \frac{4\pi A^2}{\lambda^2}$$

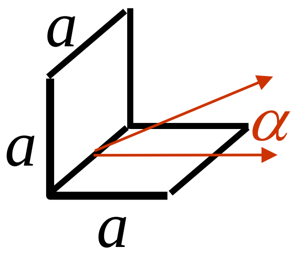
$$\frac{\sigma_\alpha}{\sigma_{45^0}} = \frac{A_\alpha^2}{A_{45^0}^2} = \frac{w^2 l_\alpha^2}{w^2 l_{45^0}^2} = 2\sin^2\alpha$$



Corner reflector (dihedral)

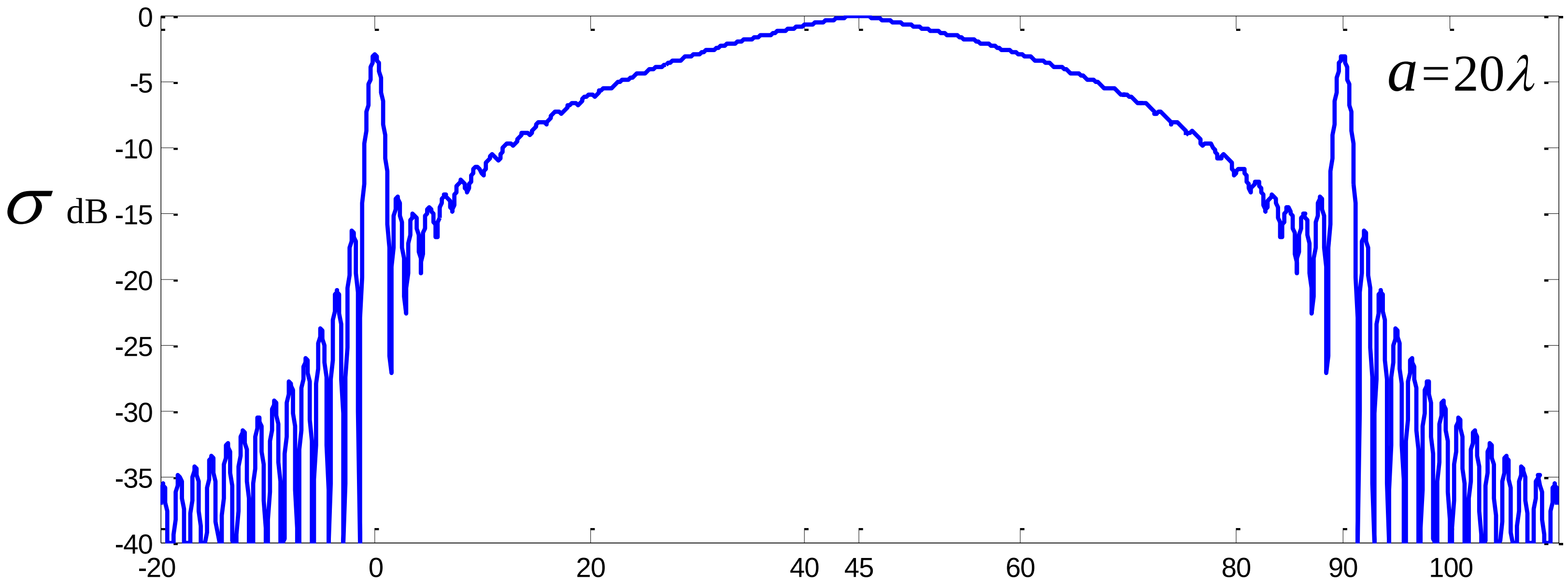
$$\sigma = \left(\sqrt{\sigma_D} + \sqrt{\sigma_{FP}}\right)^2$$

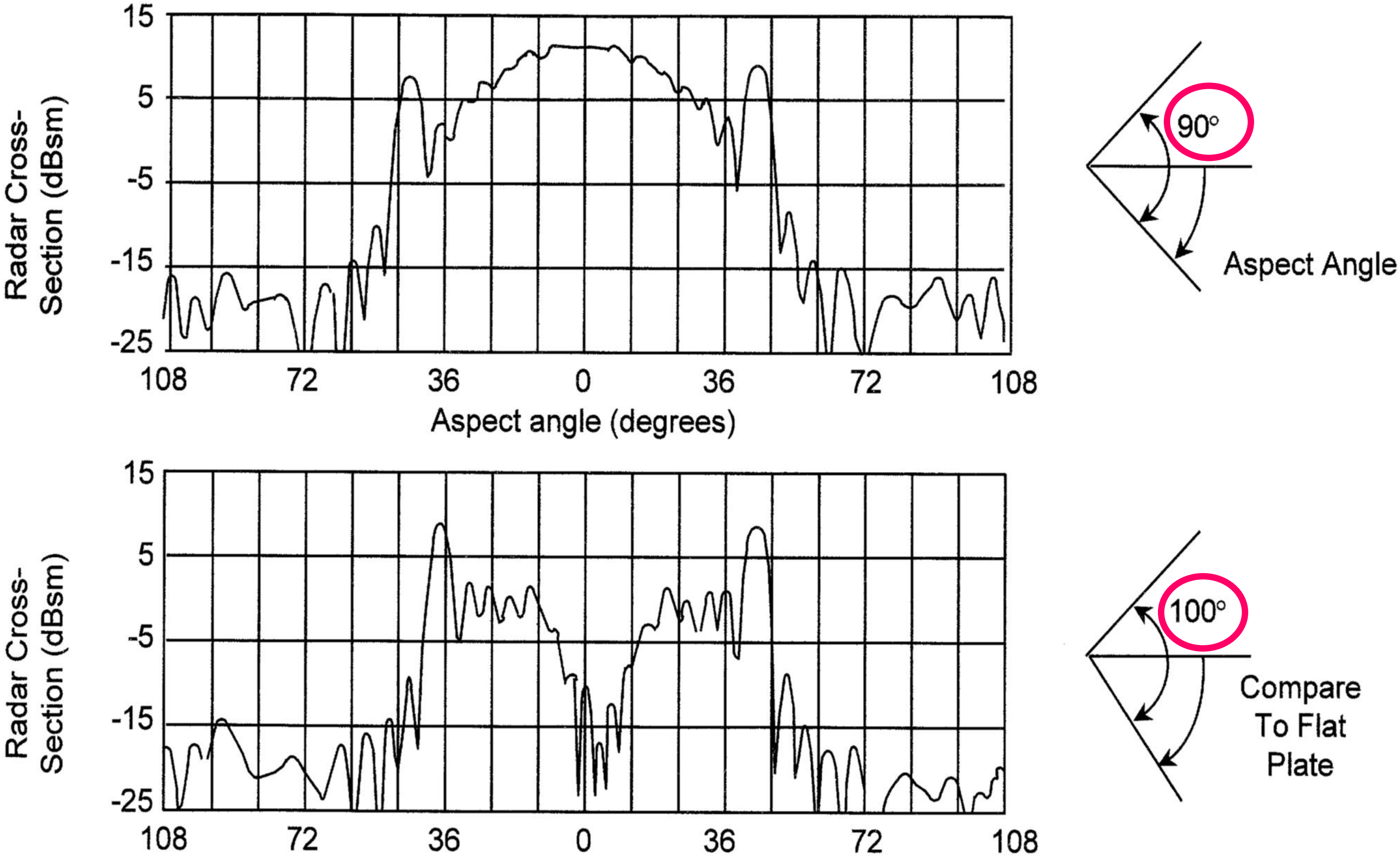
$$\sigma_D = \frac{16\pi a^4}{\lambda^2}\sin^2\alpha \ , \quad 0 \le \alpha \le 45^0 \text{, zero elswhere}$$

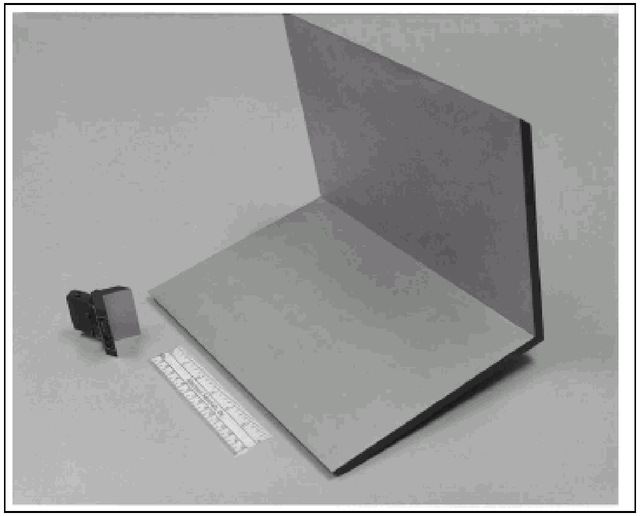


$$\sigma_{FP} = \frac{4\pi a^4}{\lambda^2}\left[\frac{\sin(ka\sin\alpha)}{ka\sin\alpha}\right]^2 \ , \quad -20^0 \le \alpha \le 45^0$$

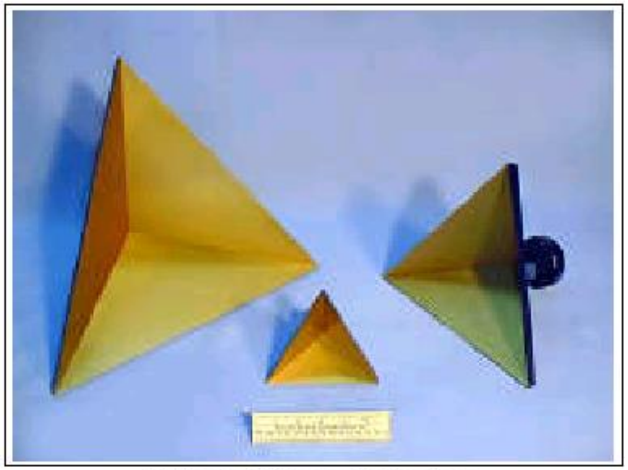
for $45^0 \le \alpha \le 90^0$ use $90 - \alpha$ instead of α



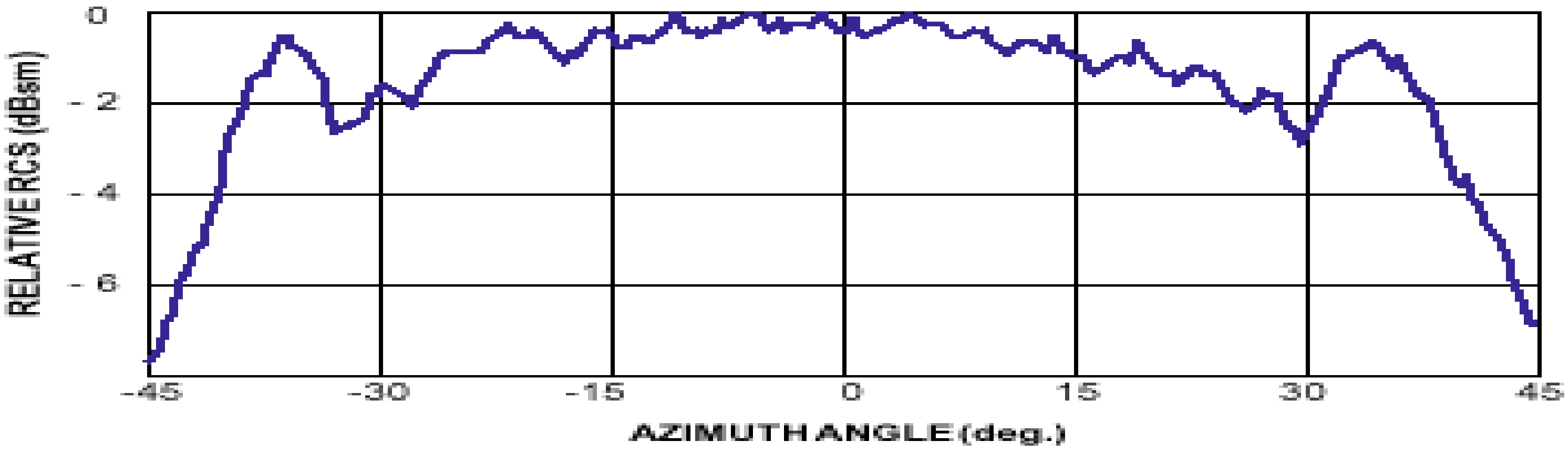

15
5
-5
-15
-25
Radar Cross-Section (dBsm)
108 72 36 0 36 72 108
Aspect angle (degrees)
90°
Aspect Angle
15
5
-5
-15
-25
Radar Cross-Section (dBsm)
108 72 36 0 36 72 108
100°
Compare To Flat Plate



Dihedral Corner Reflectors



Trihedral Corner Relectors



Typical Trihedral RCS vs. Azimuth Scattering Response

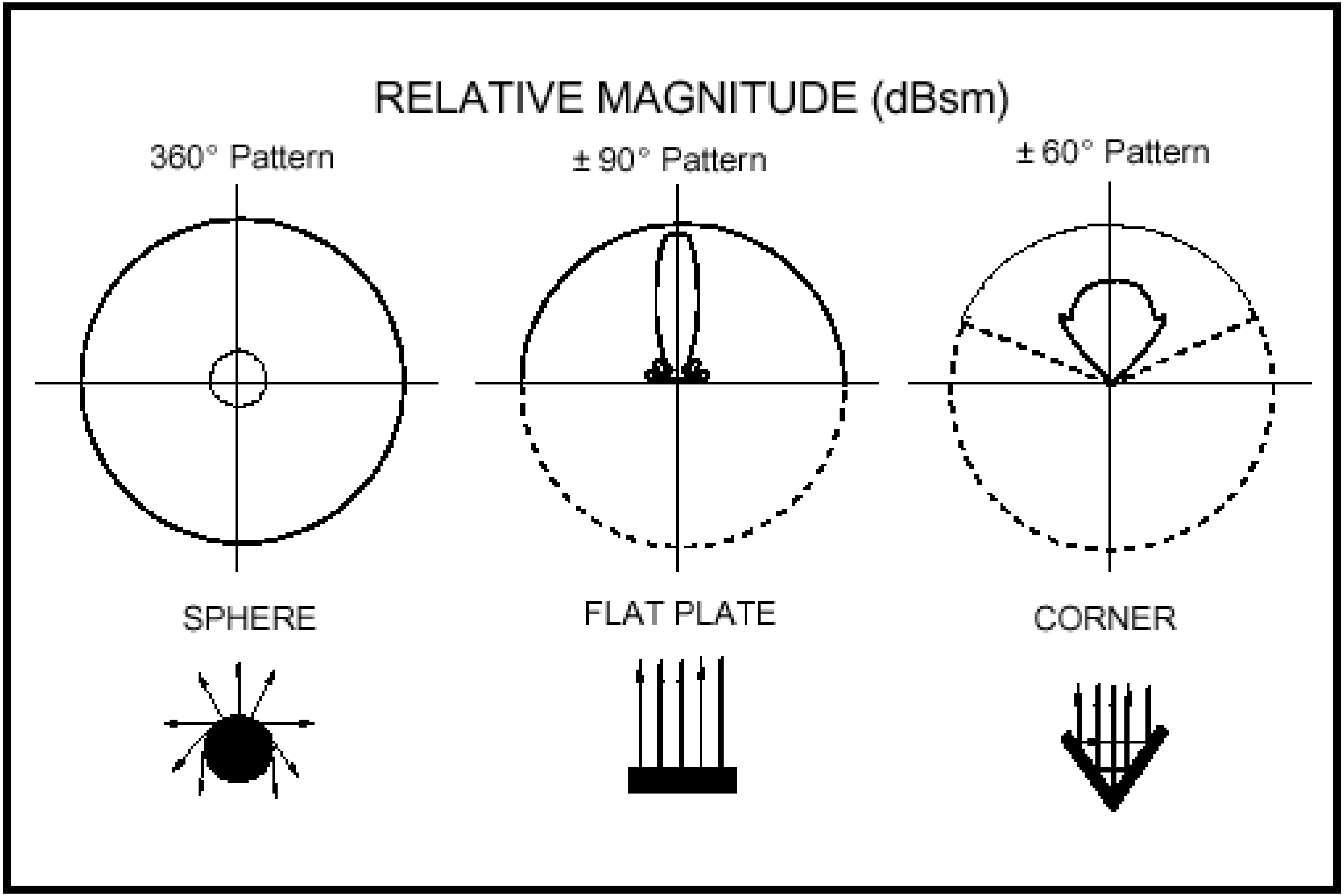
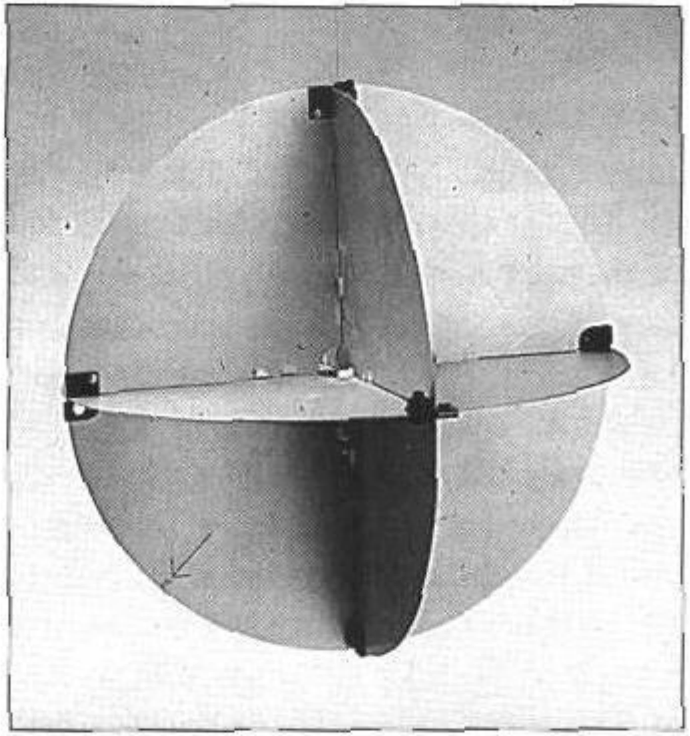
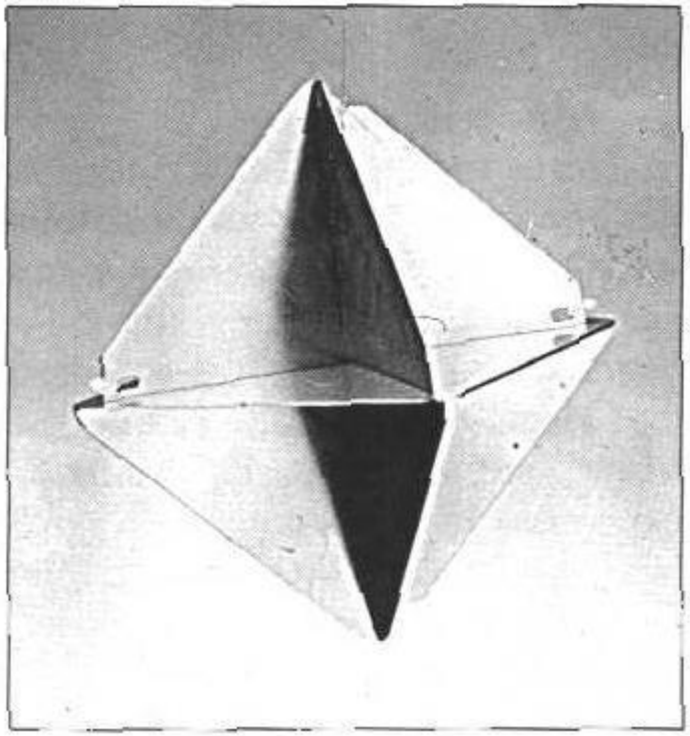
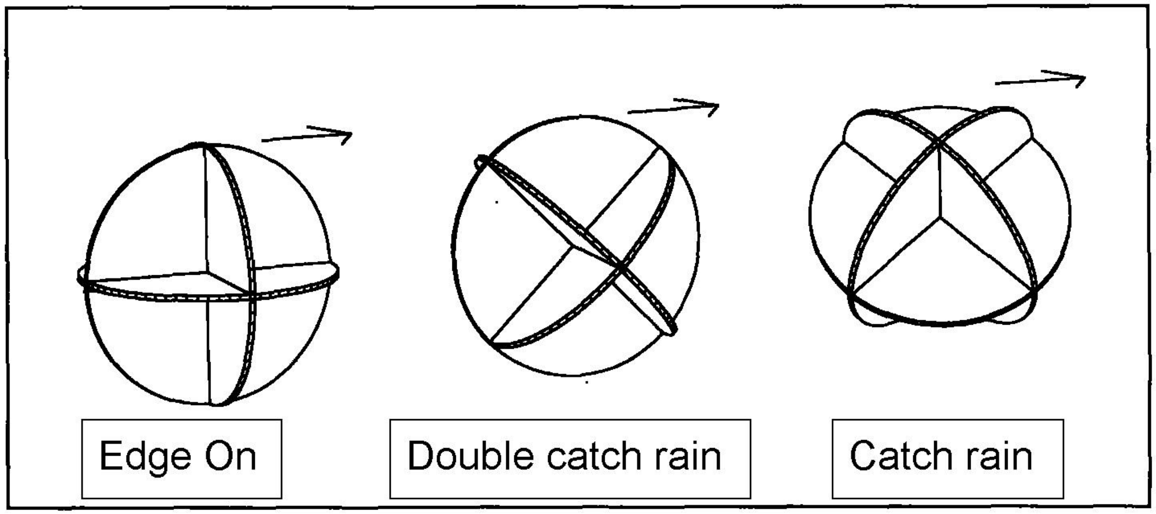


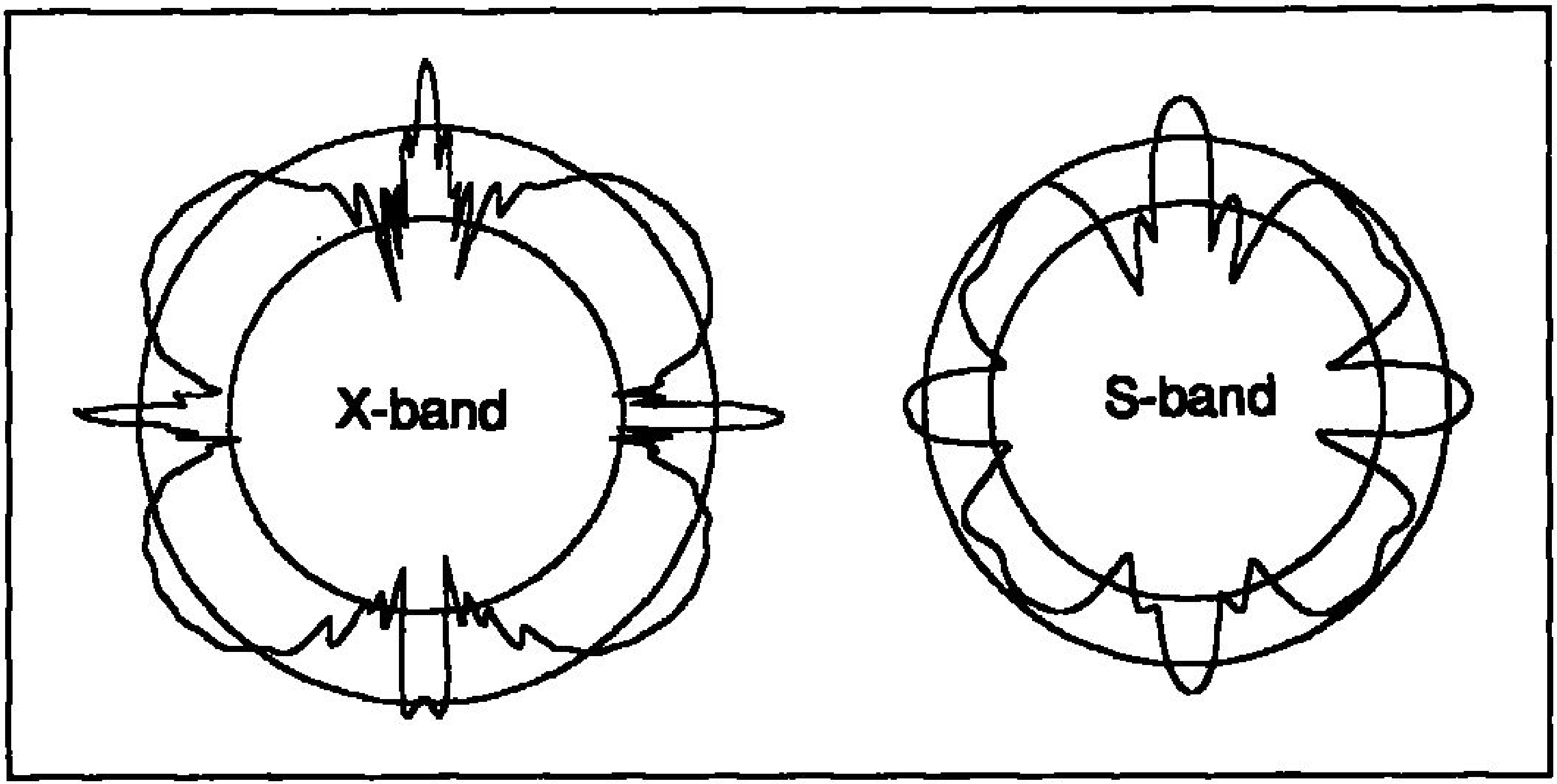
Figure 4. RCS Patterns






Edge On
Double catch rain
Catch rain

RCS pattern of radar retroflector



Davis Echomaster

The Davis Echomaster is a push fit octahedral reflector constructed from three aluminium circular panels which are slotted together, these panels are locked in placed by plastic corners pieces. This octahedral is designed to be mounted in the catch rain position, and is shown below in this position in figure 4.

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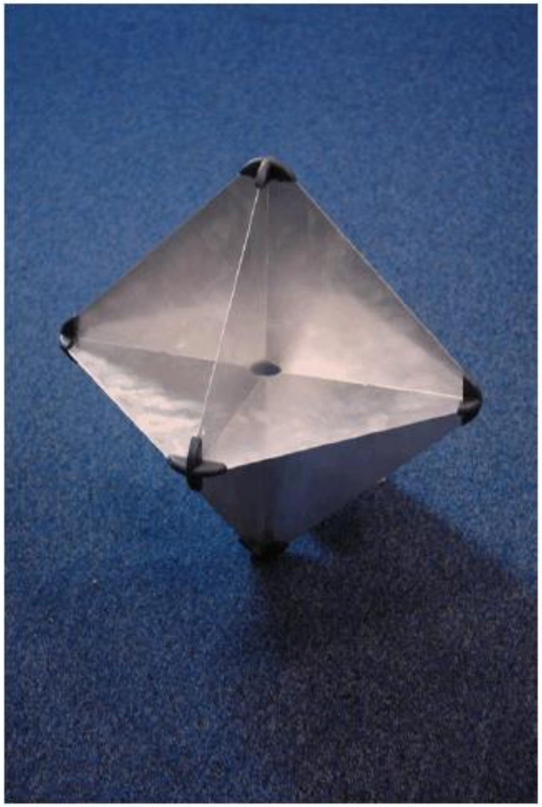
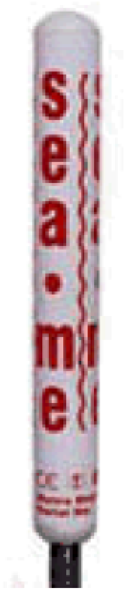
Plastimo 16” octahedral reflector

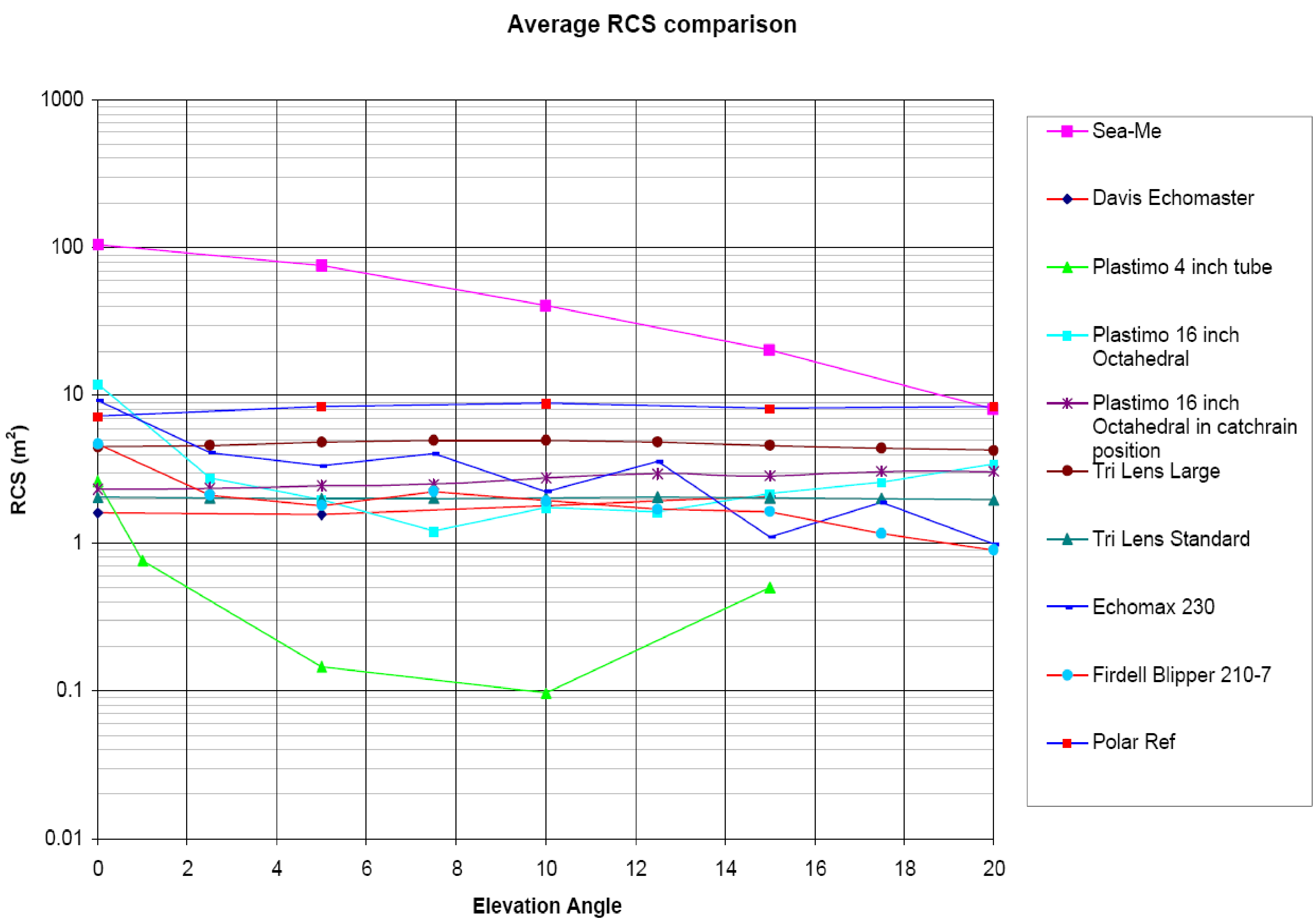
Plastimo 16” is a push fit octahedral reflector constructed from three aluminium diamonds slotted together, these panels are locked in placed by plastic corners pieces. This reflector only had mounting holes for an upright position (not the generally recommended “catch rain” position). The Plastimo 16” Octahedral reflector is pictured in this mounting position in figure 2.



Sea-me Radar Target Enhancer (RTE)

The Sea-me RTE is an active system, which receives a radar pulse, amplifies it and re-transmits it. It contains a receive antenna, amplifier and transmit antenna contained within a plastic case/radome. This transponder will only perform against X-Band radars; unlike the passive reflectors it will not offer any performance in S-Band. The Sea-me RTE is shown below in figure 9.




Average RCS comparison
1000
100
10
1
0.1
0.01
RCS (m2)
0
2
4
6
8
10
12
14
16
18
20
Elevation Angle
Sea-Me
Davis Echomaster
Plastimo 4 inch tube
Plastimo 16 inch Octahedral
Plastimo 16 inch Octahedral in catchrain position
Tri Lens Large
Tri Lens Standard
Echomax 230
Firdell Blipper 210-7
Polar Ref

Radar Reflectors for Cruising Sailboats: Why They Work, How to Evaluate Them, and What the Limitations Are (Paperback)

by Philip G. Gallman

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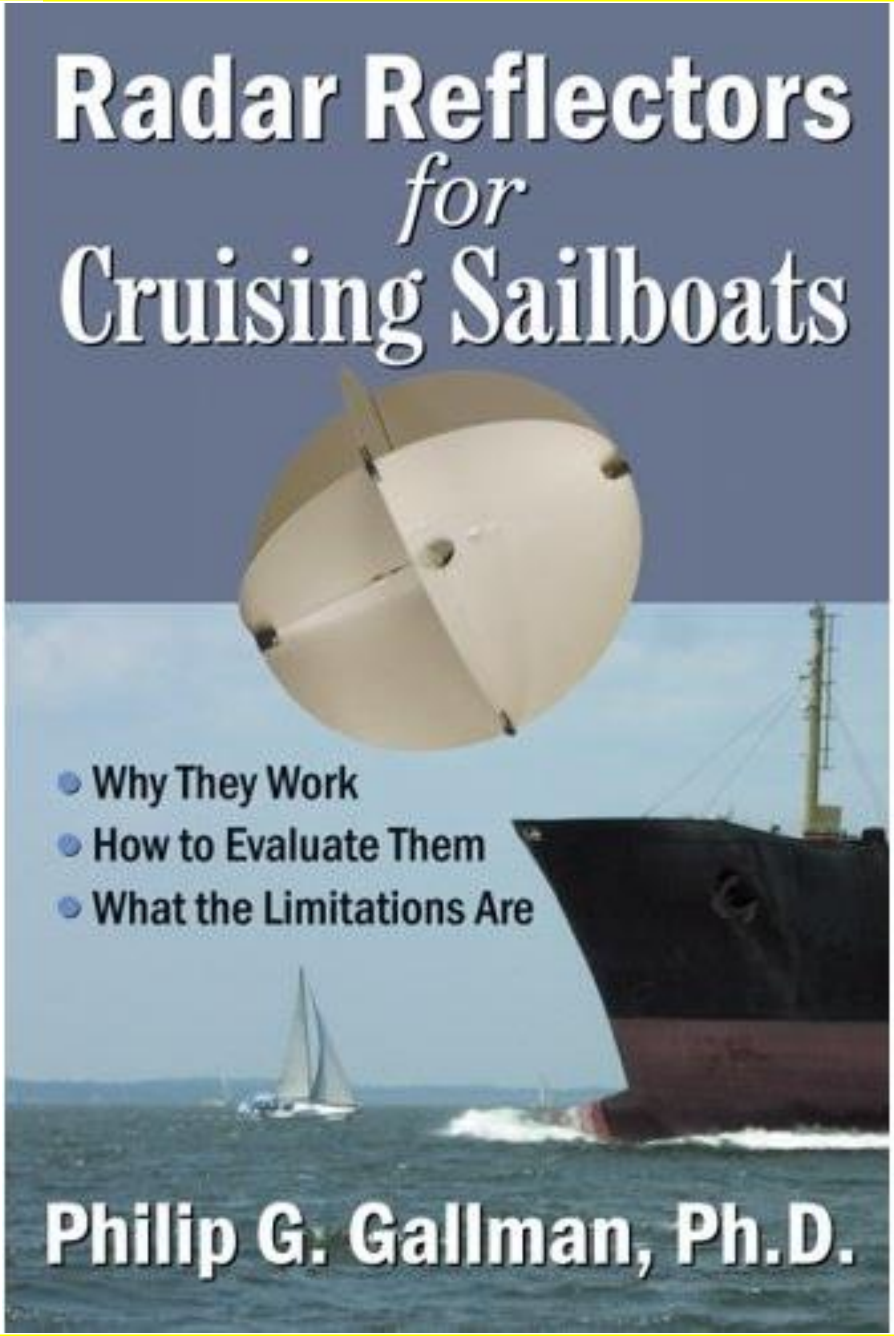
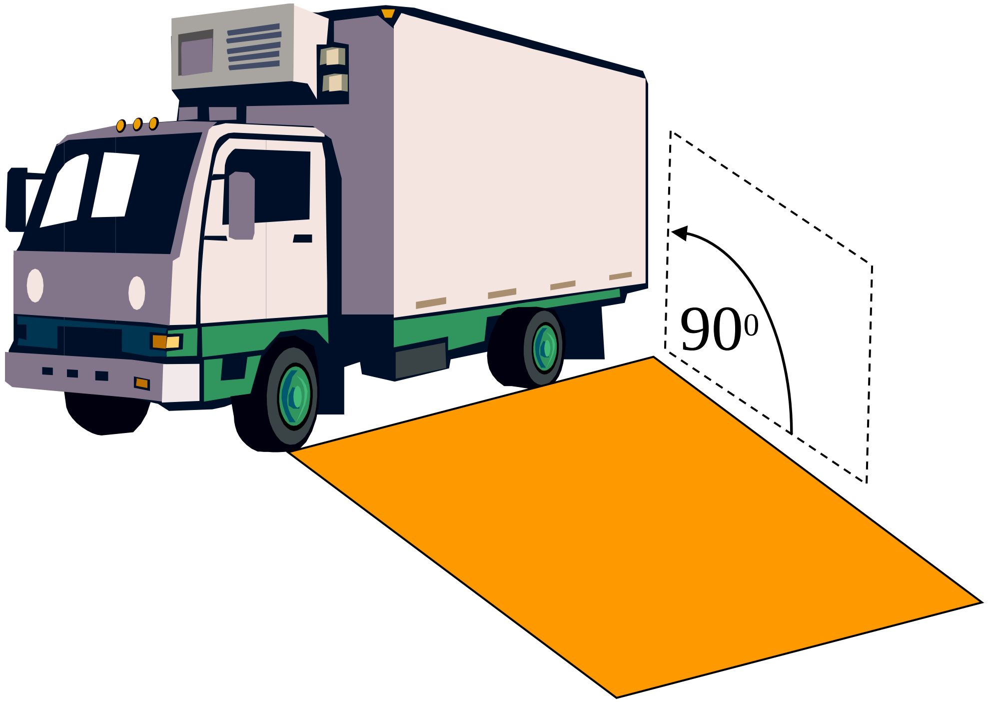
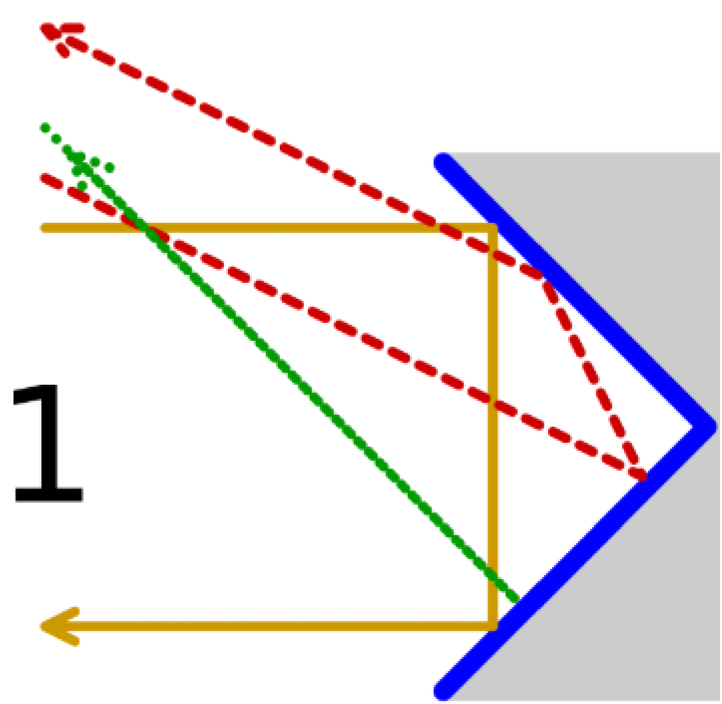


Tel Aviv marina, January 2010

Dihedrals occur often in man-made scenarios

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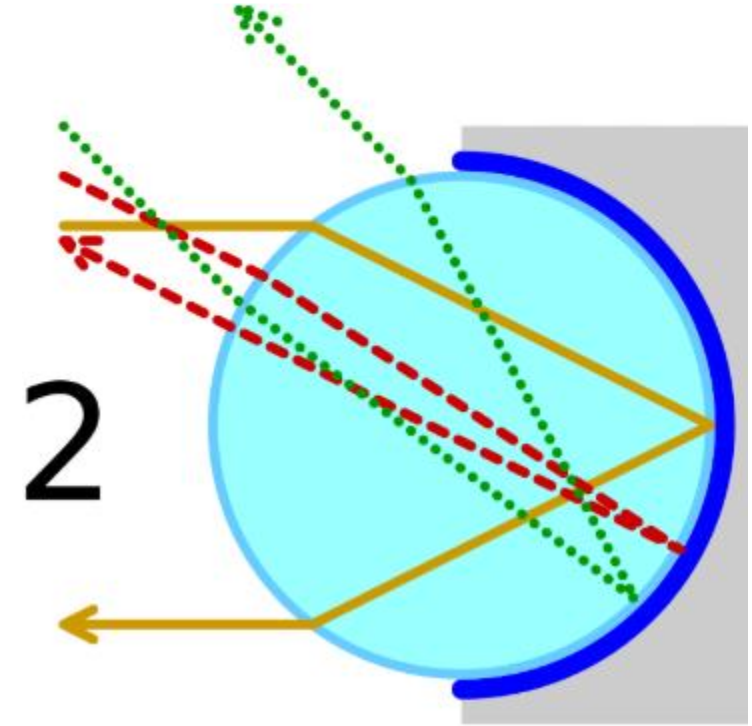
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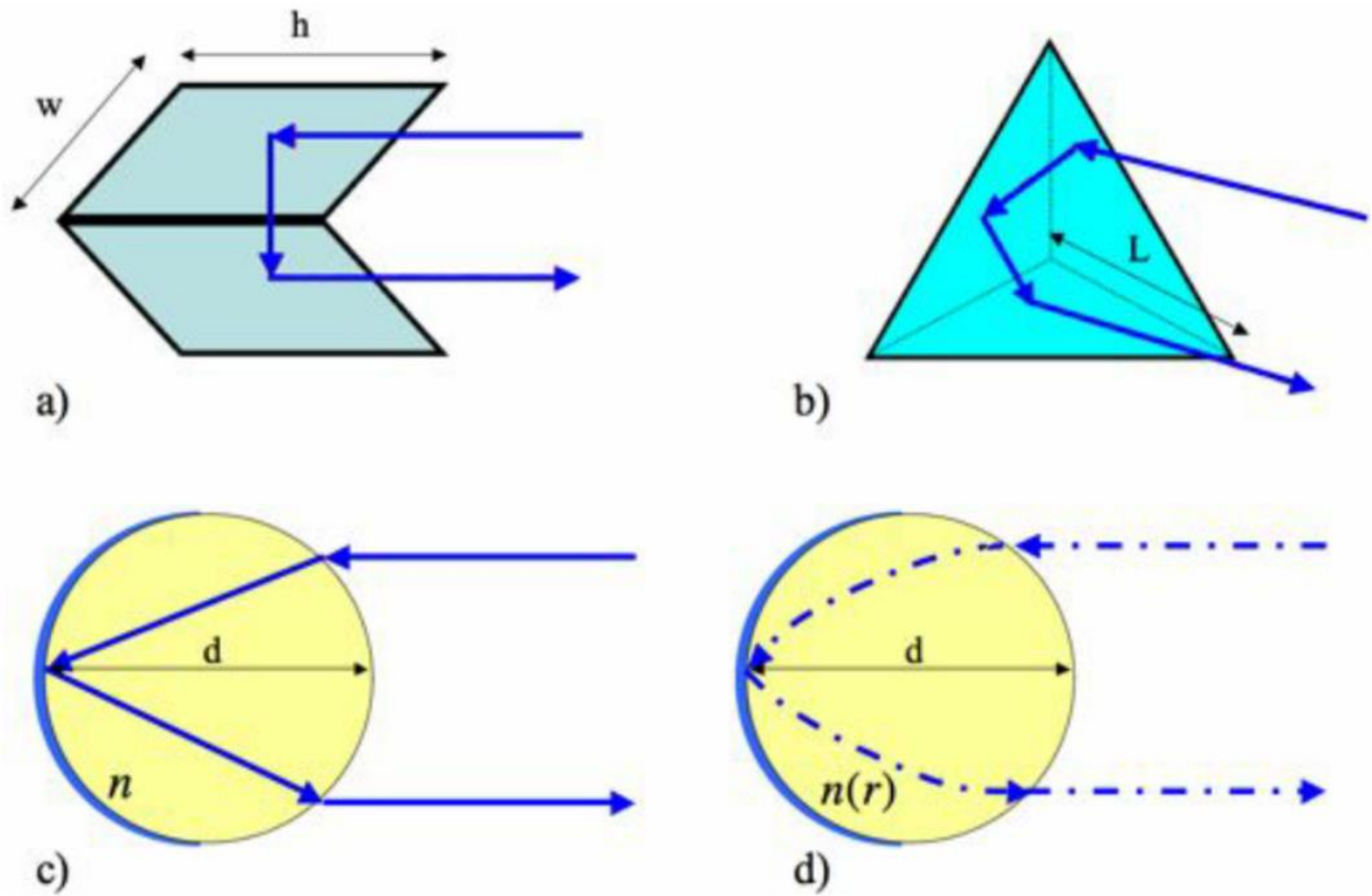

1 Common passive retroreflectors illustrating retroreflection and displaying characteristic dimensions including (a) the dihedron reflector, (b) the trihedron reflector, (c) the cat's eye reflector, and (d) the Luneburg lens reflector.

Feature Article:

DOI. No. 10.1109/MAES.2019.2944050

Additively Manufactured Luneburg Retroreflector

***Joseph C. Deroba, Kevin D. Sobczak,* Aberdeen Proving Ground, Aberdeen, USA**
***Austin Good, Zachary Larimore, Mark Mirotznik,* University of Delaware, Newark, USA**

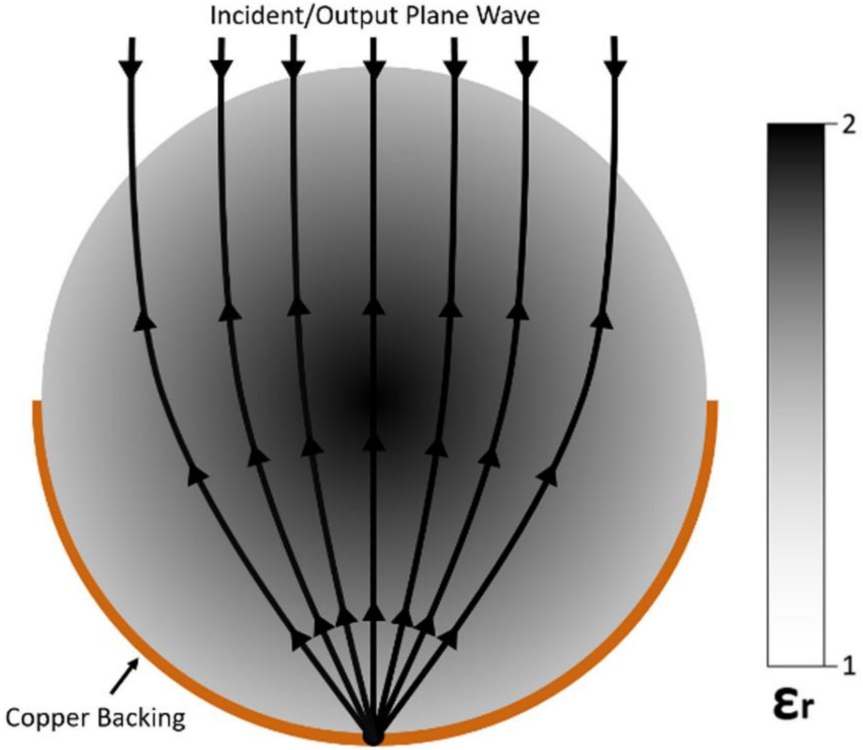

Figure 1.
Propagation of power through Luneburg lens retroreflector.

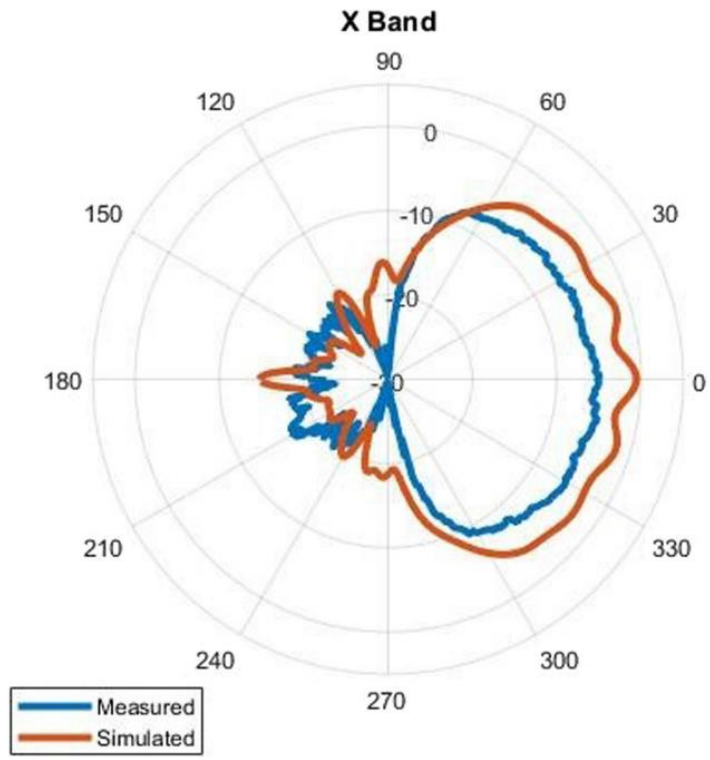

Figure 9.
Measured (blue) and simulated (orange) RCS for the additively manufactured retroreflector at 10 GHz.

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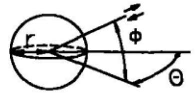
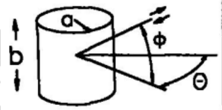
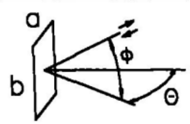
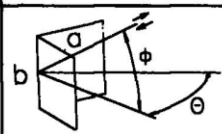
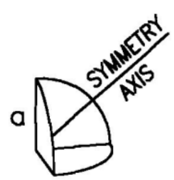
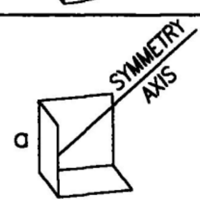
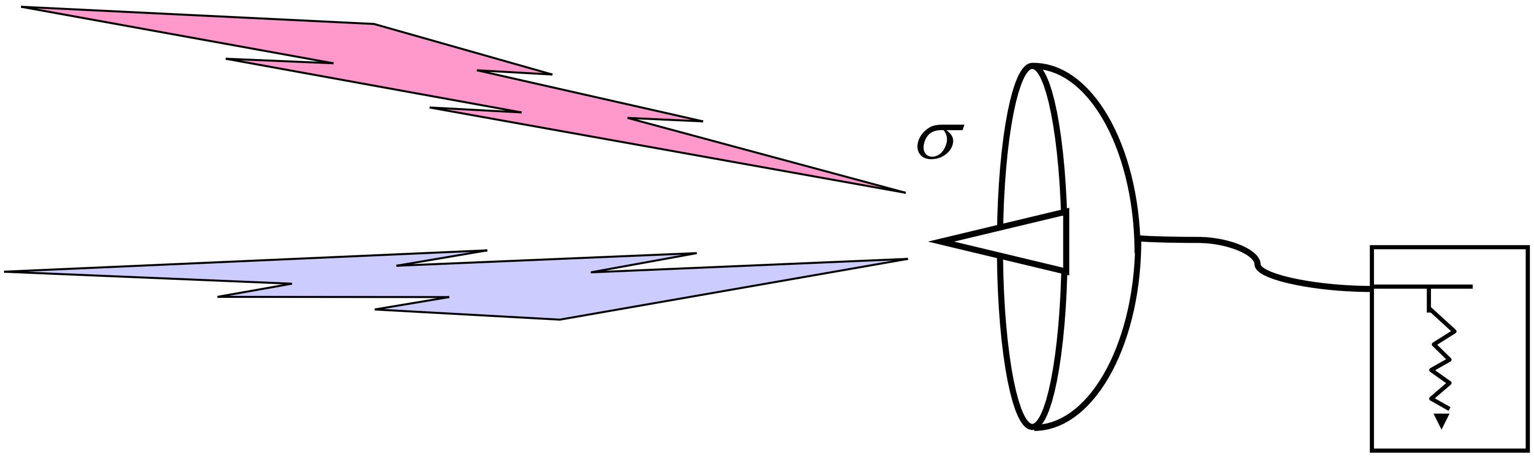
Fig. 1 Passive Radar Targets

Type	Dimensions	Maximum RCS, σ	Angular Response for σ	
			θ	$\varnothing$
Sphere		$\pi r^2 = 3.14 r^2$	360°	360°
Cylinder		$\frac{2\pi ab^2}{\lambda} = 6.28\frac{ab^2}{\lambda}$	360°	$\pm 13\frac{\lambda}{b}$ degree to $\frac{1}{2}$ max
Rectangular Flat Plate		$\frac{4\pi a^2 b^2}{\lambda^2} = 12.6\frac{a^2 b^2}{\lambda^2}$	$\pm 13\frac{\lambda}{b}$ degree to $\frac{1}{2}$ max	$\pm 13\frac{\lambda}{b}$ degree to $\frac{1}{2}$ max
Rectangular Dihedral Corner		$\frac{8\pi a^2 b^2}{\lambda^2} = 25.1\frac{a^2 b^2}{\lambda^2}$	$\pm 15°$ to $\frac{1}{2}$ max $\pm 32°$ to $\frac{1}{10}$ max	$\pm 13\frac{\lambda}{a}$ degree to $\frac{1}{2}$ max
Triangular Trihedral		$\frac{4\pi a^4}{3\lambda^2} = 4.19\frac{a^4}{\lambda^2}$	Approx. 40° total cone angle about axis to $\frac{1}{2}$ max	
Circular Trihedral		$15.6\frac{a^4}{\lambda^2}$	Approx. 32° total cone angle about axis to $\frac{1}{2}$ max	
Square Trihedral		$\frac{12\pi a^4}{\lambda^2} = 37.8\frac{a^4}{\lambda^2}$	Approx. 23° total cone angle about axis to $\frac{1}{2}$ max	

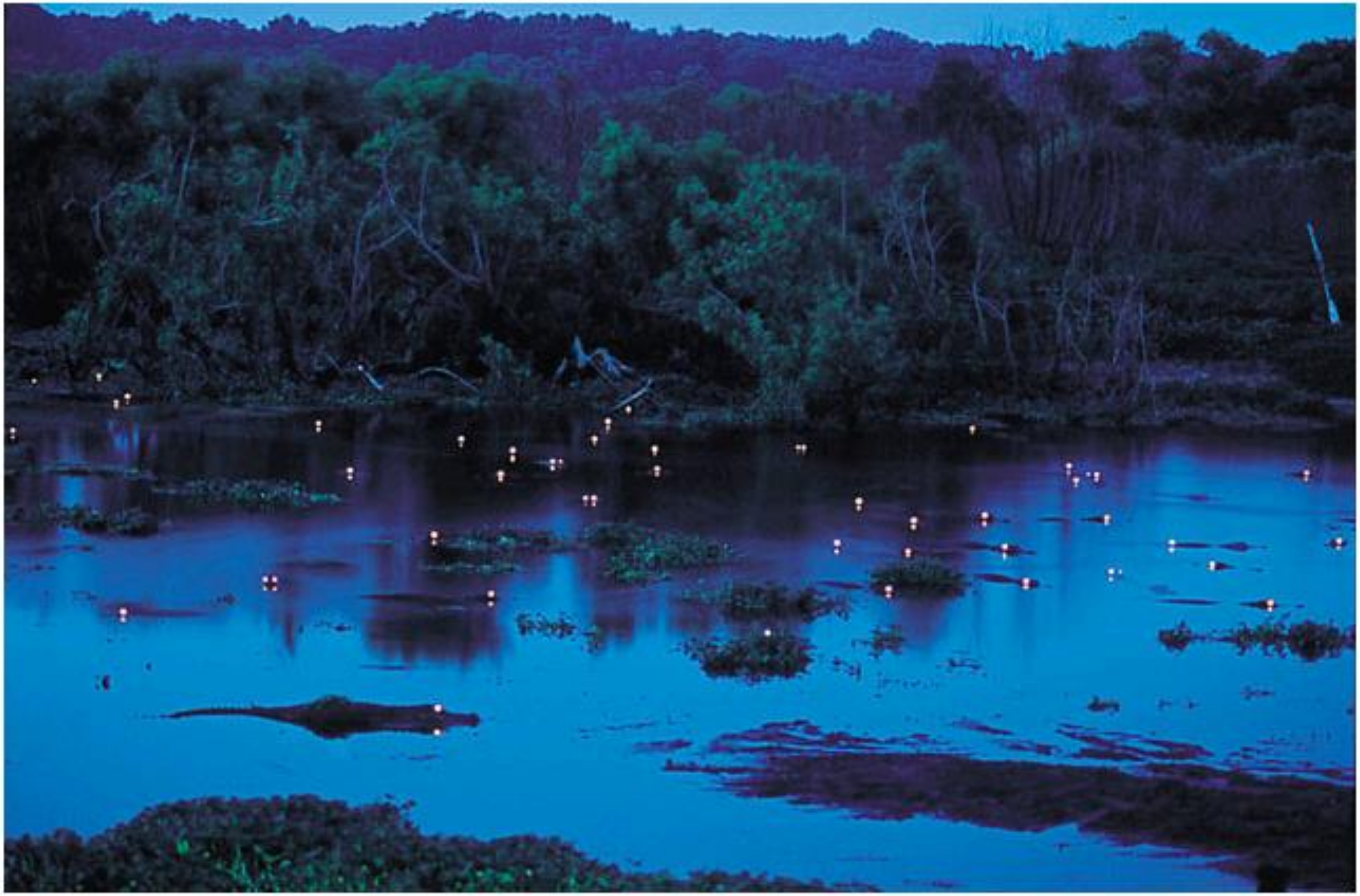
RADAR CROSS SECTION OF ANTENNAS



$$\sigma = \left[\sqrt{\sigma_{\text{structure}}} + \sqrt{\sigma_{\text{antenna mode}}} \exp(j\phi) \right]^2$$

Antenna mode exhibits a very large RCS, if the antenna gain pattern points toward the radar and there is some mismatch in the load.

Alligators at dusk, Payne's Prairie State Preserve, Florida.



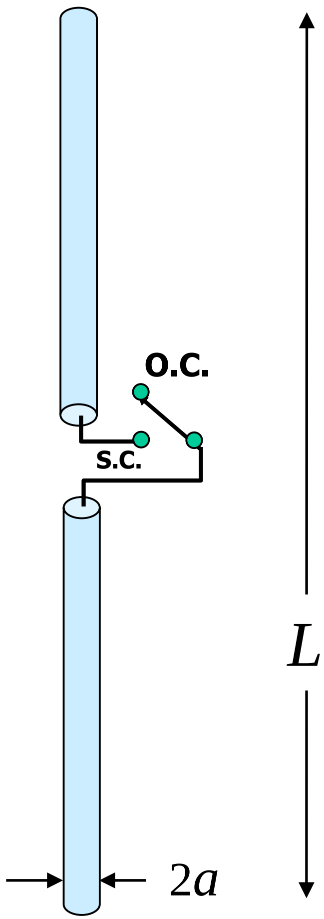
Courtesy John Moran, The Gainsville Sun ©

$$\sigma_{sc} \approx \frac{0.176\lambda^2}{1+12^2(kL)^{-6}\left[3\ln(2L/a)-7\right]^2}\,,\quad \frac{L}{\lambda}<0.4$$

$$\sigma_{oc} \approx \frac{\lambda^2(kL)^6}{96\pi^2\left[\ln(2L/a)-2\right]^2}\,,\quad \frac{L}{\lambda}<0.8\,,\quad k=\frac{2\pi}{\lambda}$$

$$\left.\begin{aligned} L_{\text{resonance, sc}} &\approx 0.45\lambda \\ L_{\text{resonance, oc}} &\approx 0.87\lambda \end{aligned}\right\} \sigma_{\text{resonance}} = 0.716\lambda^2$$

$$\frac{L}{a}=150,\quad \frac{L}{\lambda}=0.45 \quad \Rightarrow \begin{cases} \dfrac{\sigma_{sc}}{\lambda^2}=0.716 \\ \dfrac{\sigma_{oc}}{\lambda^2}=0.002\ (-26\text{dB}) \end{cases}$$



$$\sigma_{\text{resonance}} = 0.716\lambda^2 = \frac{1.5^2}{\pi}\lambda^2$$

$$G_{\text{dipole}} = 1.5$$

$$\sigma_{\text{resonance}} = \frac{G^2}{\pi}\lambda^2$$

Good approximation for many antennas

A Tutorial on the Receiving and Scattering Properties of Antennas

***Steven R. Best*[1] *and Bradley C. Kaanta*[2]**

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[2]Boston University
1 Sherborn Street, Boston, MA 02215 USA
E-mail: kaanta@bu.edu

Abstract

A tutorial discussion on the receiving and scattering properties of antennas is presented. The objective of this work is to provide a comprehensive tutorial overview of the subject, in conjunction with circuit calculations and numerical simulations that illustrate the fundamental concepts of how antennas behave as both receivers and scatterers of electromagnetic fields and power. The paper begins with a discussion of the basic concepts associated with antenna impedance, as these are fundamental to understanding the antenna's receiving and scattering properties, particularly over a wide range of frequencies, where the circuit properties of the antenna differ. The definitions of aperture efficiency, absorption efficiency, and the validity of using either a Thevenin or Norton equivalent circuit to determine both received and total scattered power are discussed. Circuit calculations and numerical simulations, determining both total received and scattered powers, are presented for a number of antennas, including a straight-wire dipole, a circular loop, a reflector-backed dipole, and a Yagi antenna. We show that Thevenin and Norton equivalent circuits have limited validity when used to determine the total power scattered by a basic antenna element such as the dipole and loop. For the general antenna, these equivalent circuit models are not valid for determining the total scattered power.

Keywords: Antennas; antenna theory; antenna radiation patterns; dipole antennas; loop antennas; Yagi-Uda arrays; scattering

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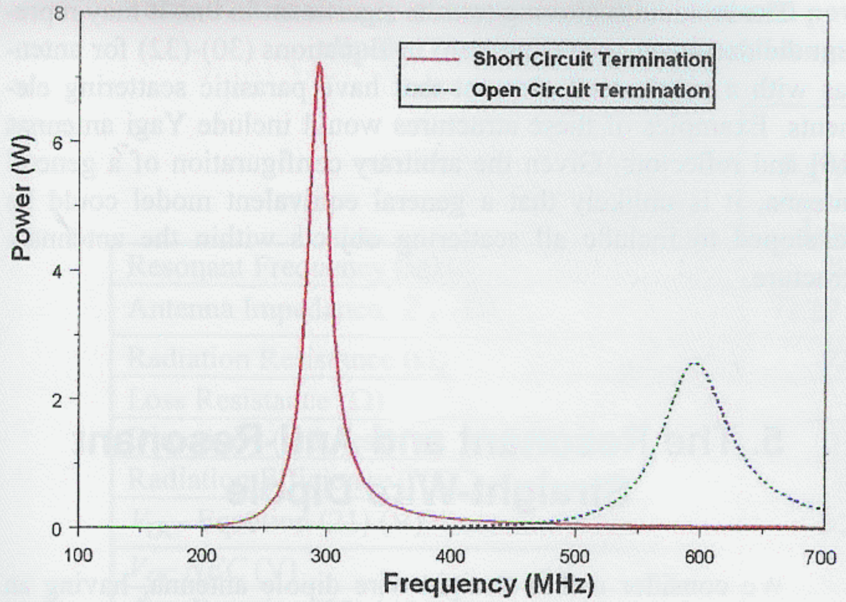


Figure 5. The total power scattered by the 0.5 m dipole as a function of frequency with its feed point terminated with an open-circuit and a short-circuit.

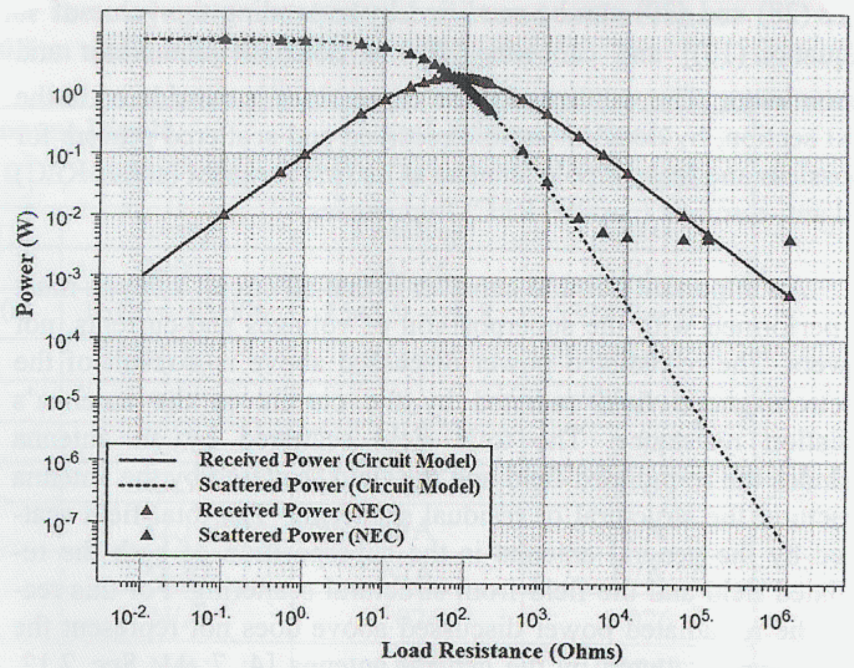
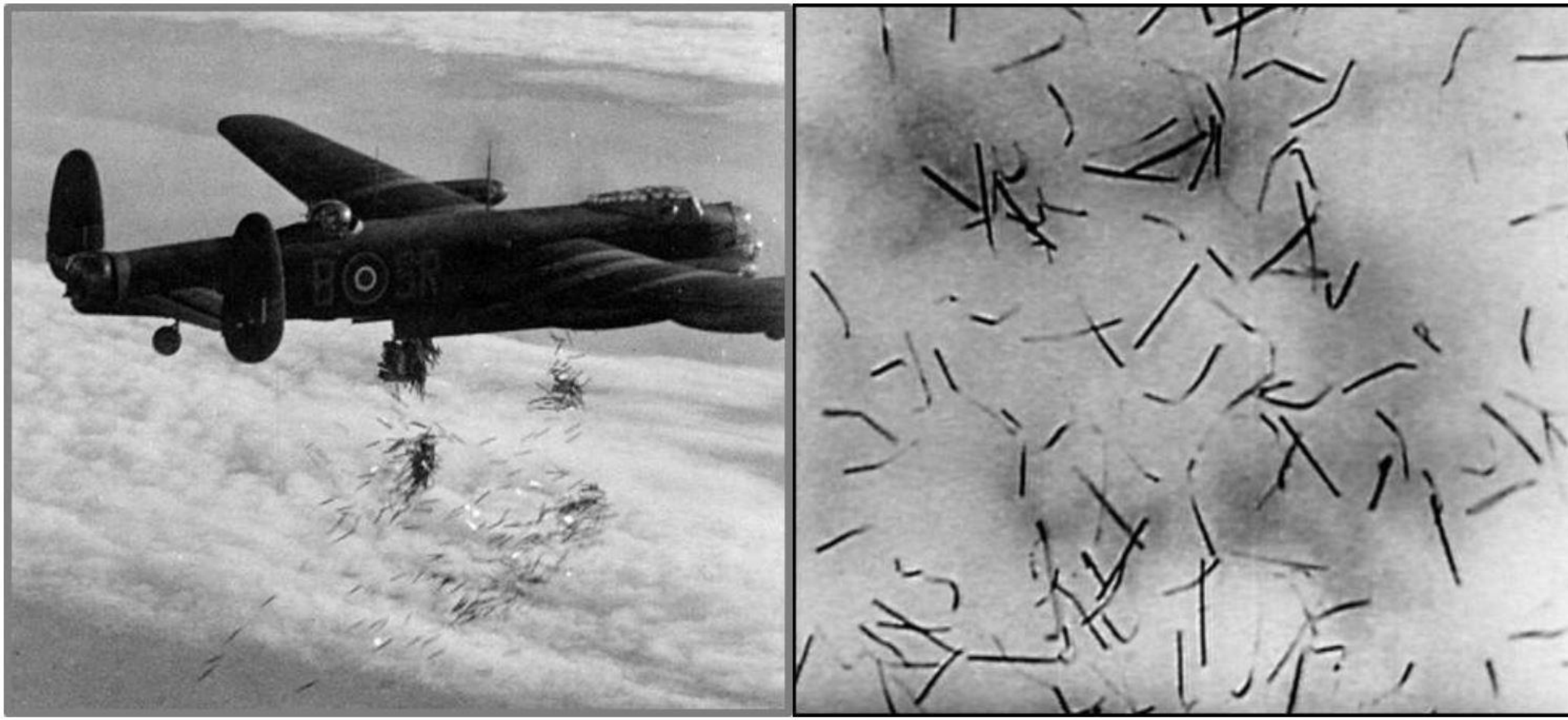


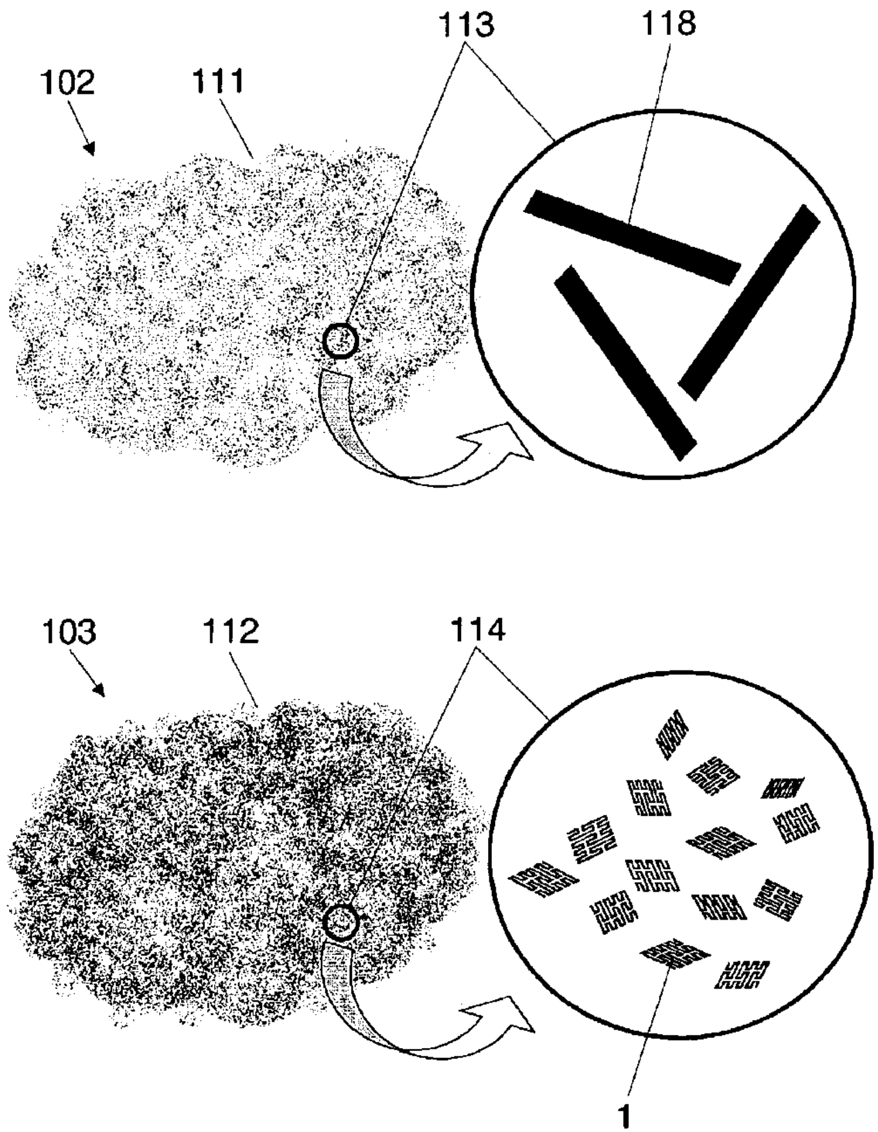
Figure 6. The received and total scattered powers for the loss-less, resonant dipole, determined using the circuit models and *NEC4*.

CHAFF – WW2 counter-measure



Chaff, deployed from an RAF Lancaster bomber.

Chaff cartridges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Measurement of CHAFF RCS

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Abstract: *In the opening part, the article describes the topic of passive radar jamming and the possibilities of using dipole reflectors (Chaff) to provide radar camouflage. The article further describes the design of an experiment used to determine the values of radar cross-section (RCS) for several Chaff samples. The conclusion shows the practical implementation of the experiment, assesses the RCS values and comments on the results.*

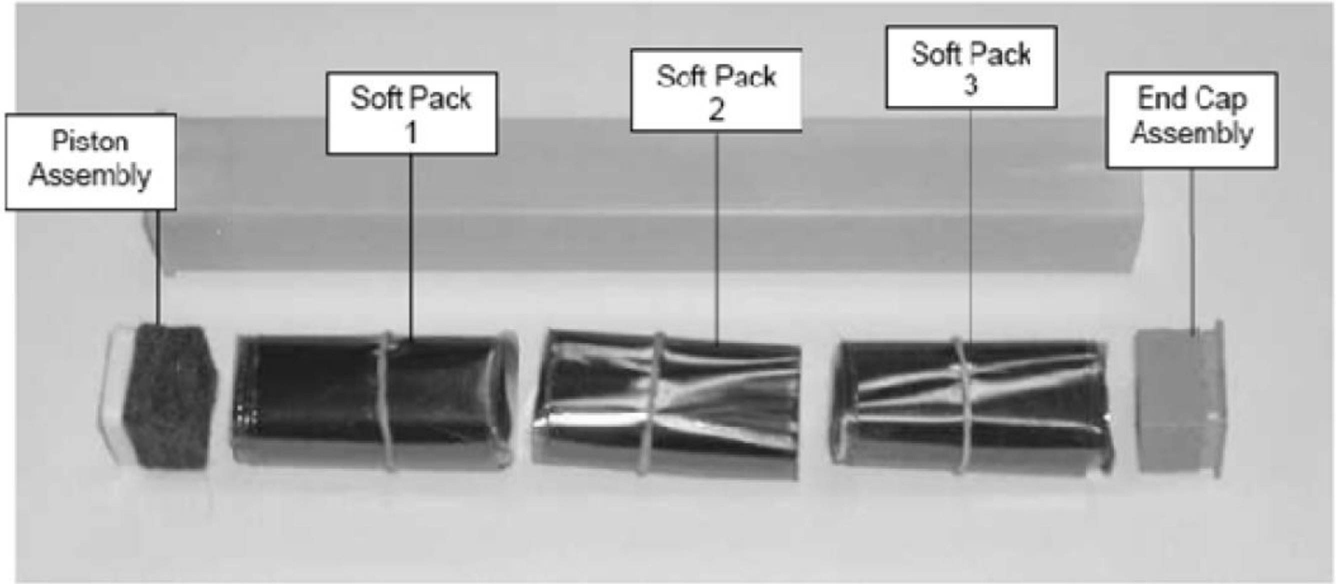


Figure 3. Cartridge with a square cross-section and three packs of dipole reflectors [4]

Example technical parameters of the Chaff cartridge from sample X2:

- Dimensions: 26 mm × 77 mm
- Dipoles diameter: 28 ± 4 microns
- Weight: 76 g
- E-glass fibre coated with aluminium and an anti-aggregation layer
- Aluminium of at least 99% purity
- Max. resistance 3.9 Ω / cm
- Weight: 40 g
- Length: 64 mm available for various section sizes

In practical cases, the mean radar cross-section of a single dipole reflector with arbitrary spatial orientation is considered to be [2]:

$$\bar{\sigma}_{\lambda/2} = 0{,}17\lambda^2 \qquad (1)$$

If the RCS of a single dipole reflector is known, it is possible to determine the number of dipole reflectors needed to create the same radar cross-section as the one of the target:

$$N = \frac{\sigma_T}{0{,}17\lambda^2} \qquad (2)$$

N – number of dipole reflectors needed to produce the required value
σ_T – radar cross-section of the target

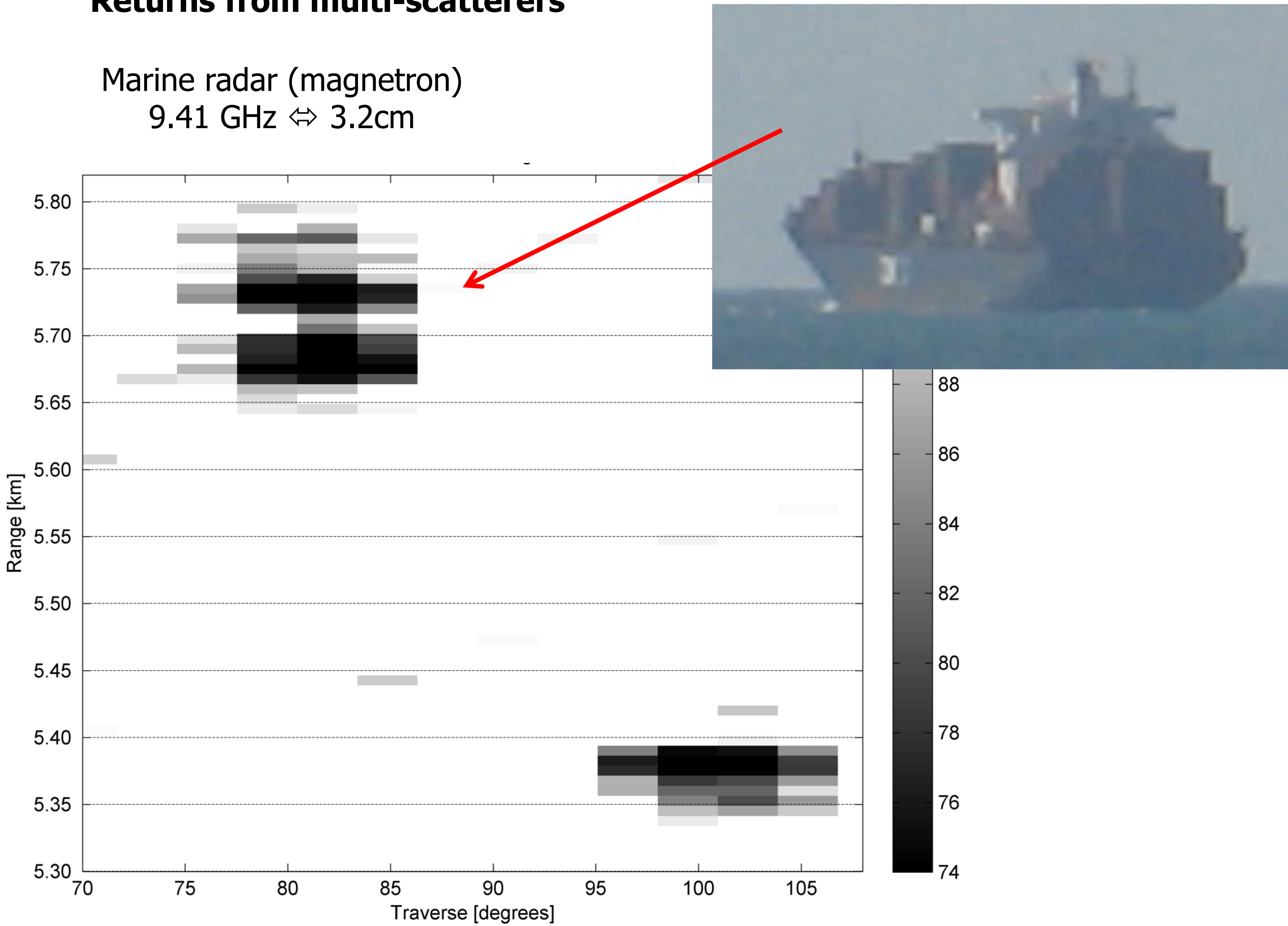
N ≅ 34417 pcs …for the lower weight limit
N ≅ 30023 pcs …for the upper weight limit

For the X1 sample at the basic effective frequency of 2.9 GHz (λ = 104 mm), the real RCS value determined with respect to the formula (4) is:

$\sigma = 0.17\,\lambda^2 N \sim 58 m^2$ for the mean value
$\sigma = 0.17\,\lambda^2 N \sim 63 m^2$ for the lower weight limit
$\sigma = 0.17\,\lambda^2 N \sim 55 m^2$ for the upper weight limit

Returns from multi-scatterers

Marine radar (magnetron)
9.41 GHz ⇔ 3.2cm



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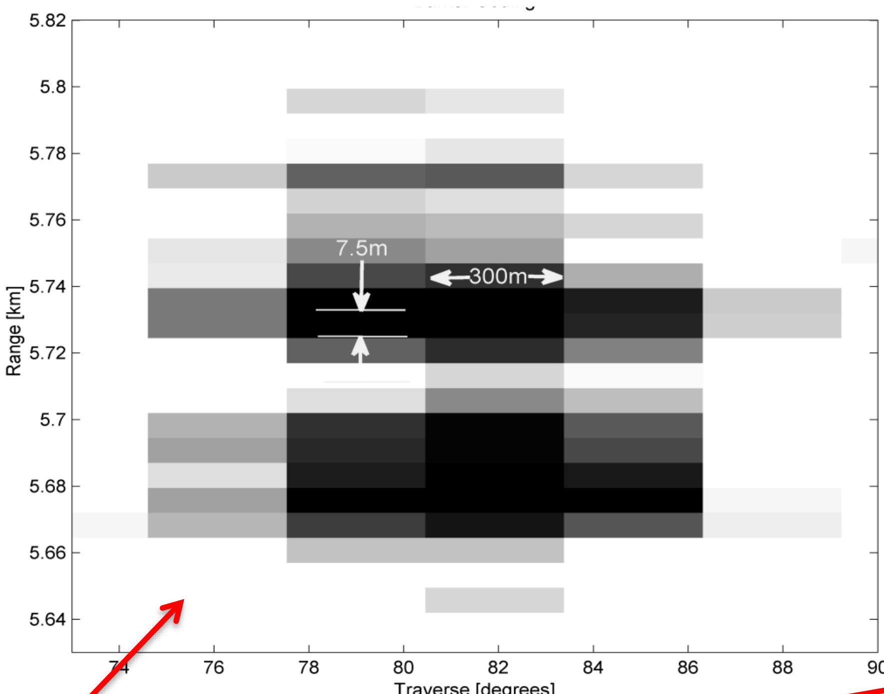
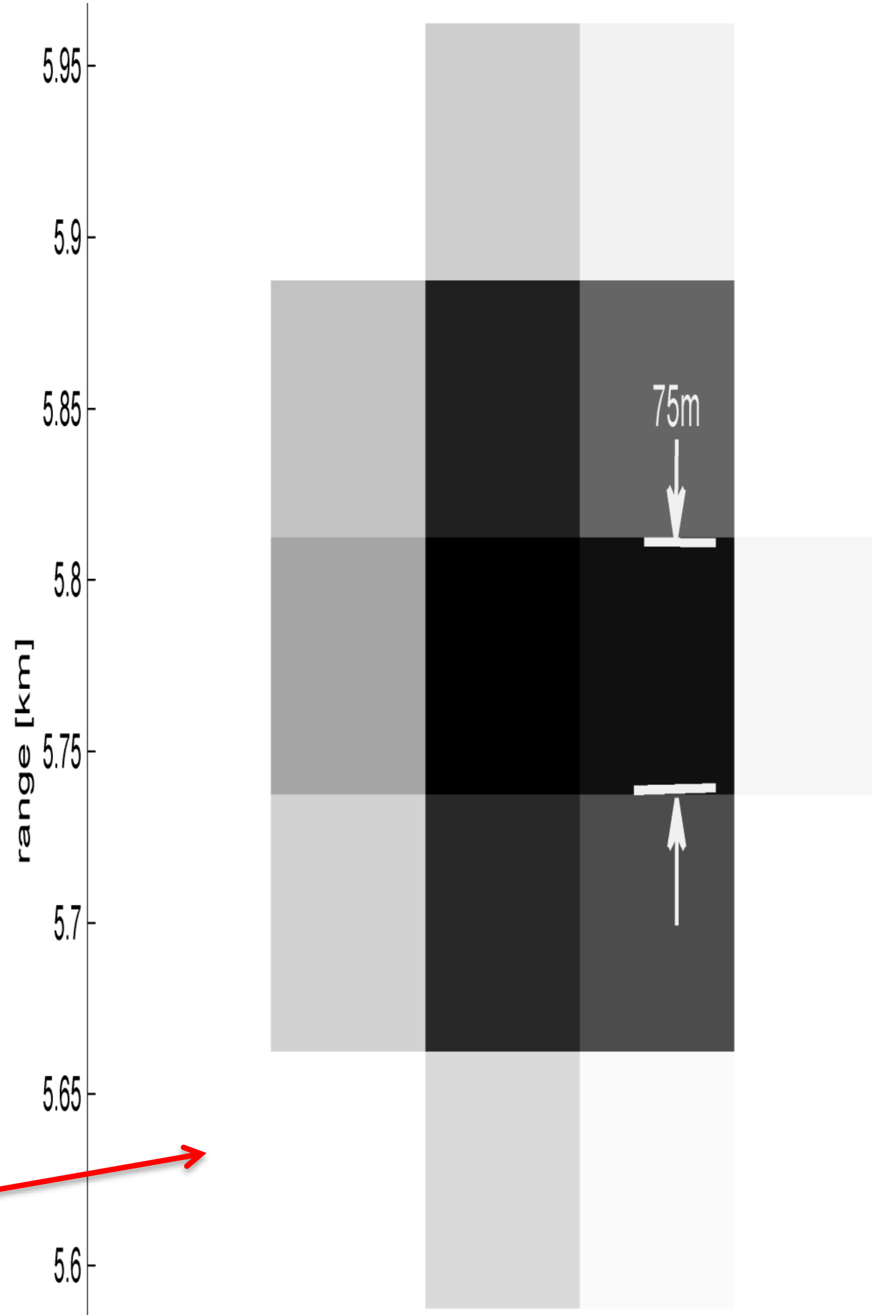
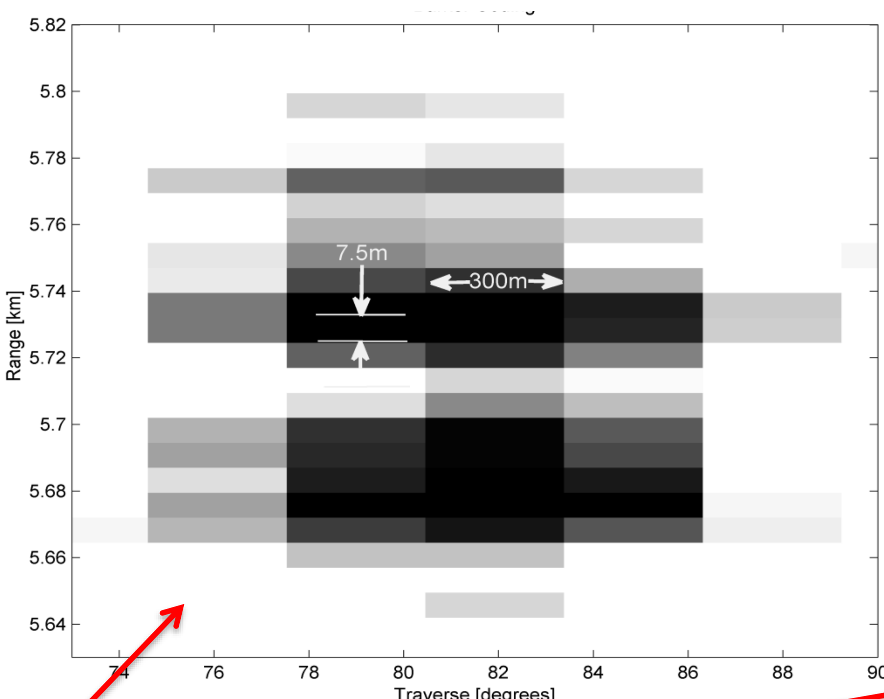
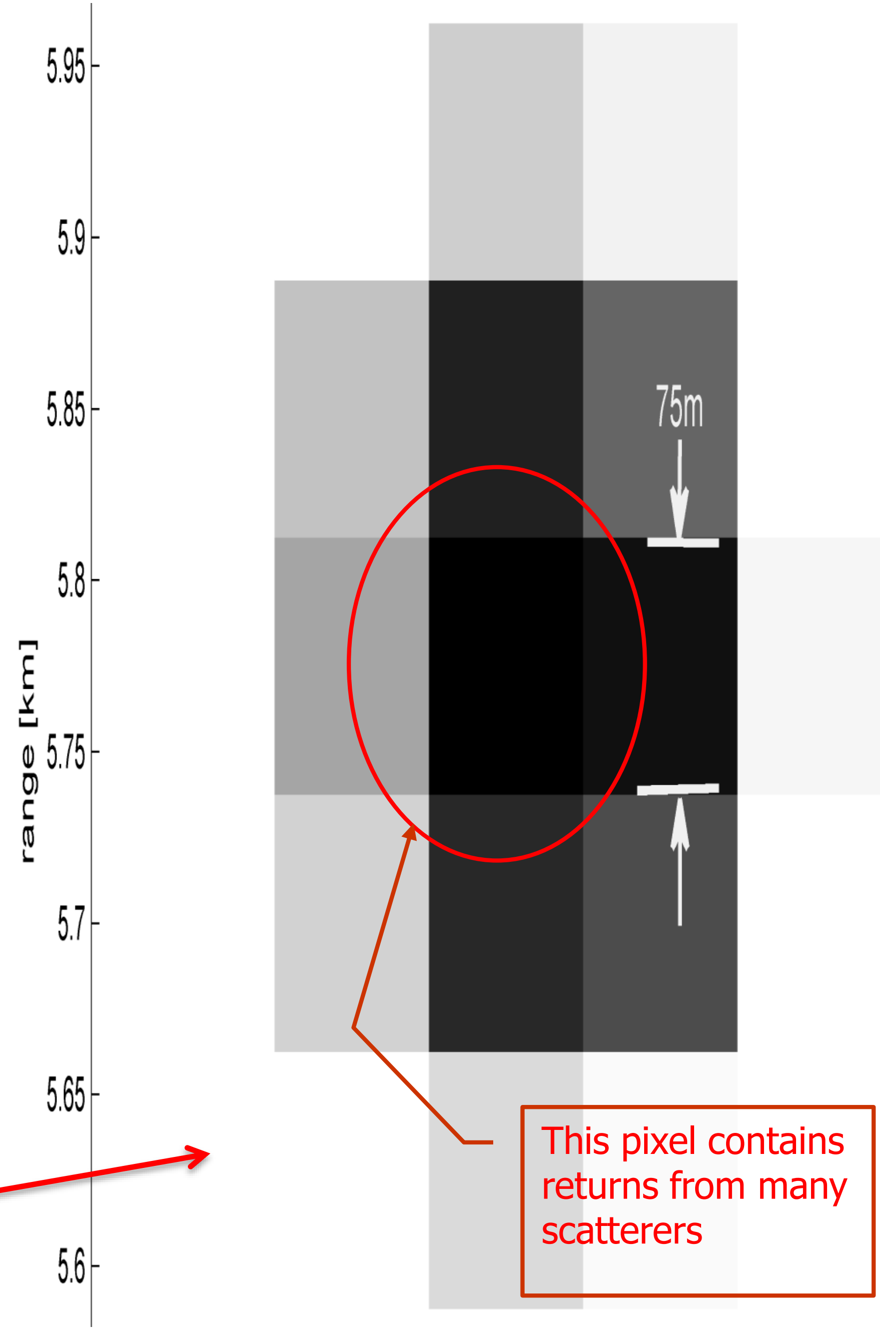




80 ns pulse = 12m, 6.2^0 beamwidth, 800 ns pulse = 120m





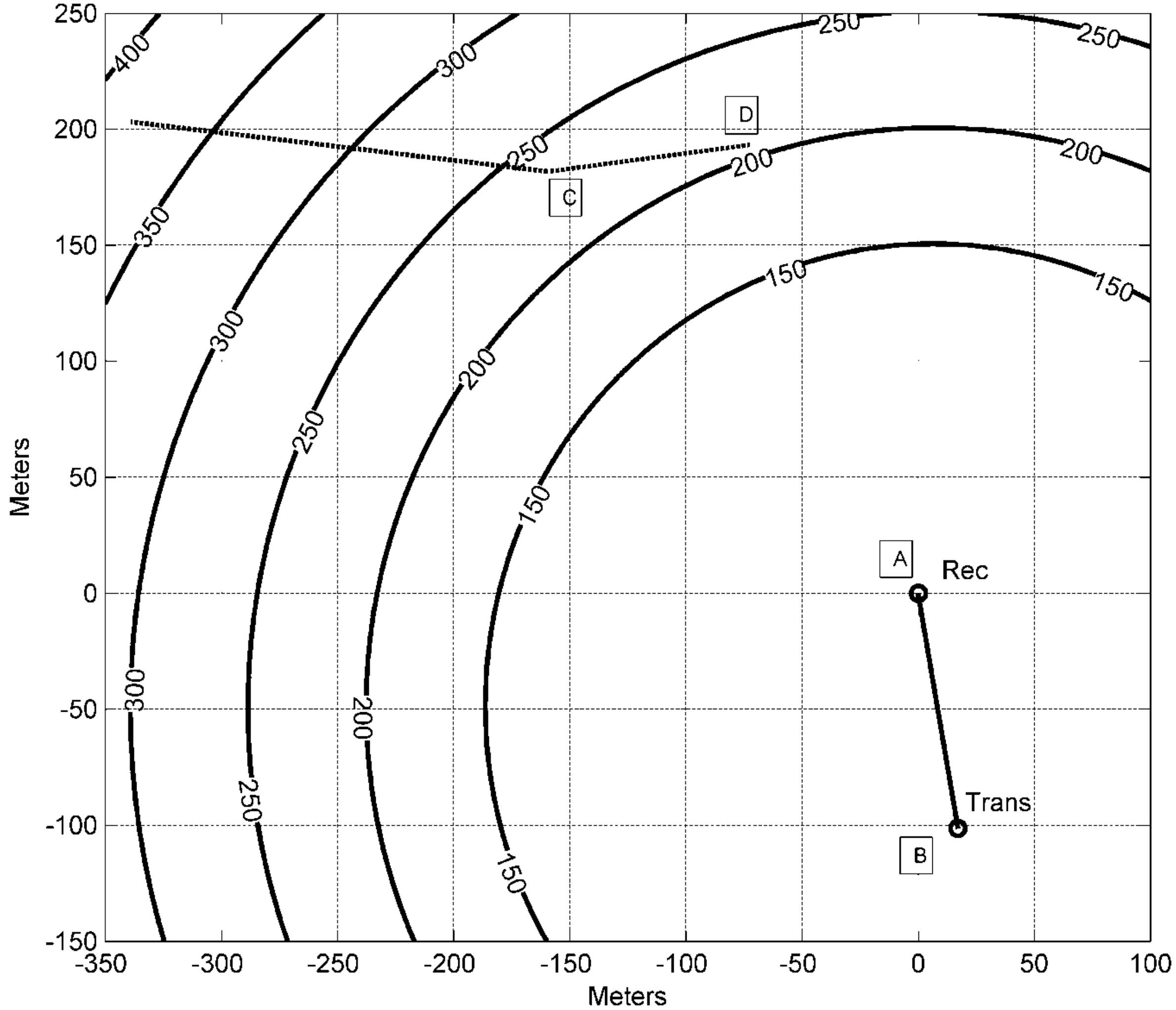
80 ns pulse = 12m, 6.2^0 beamwidth, 800 ns pulse = 120m

Sometimes only motion and coherent processing can reveal the existence of different dominant scatterers in the target(s)

June 2014 test – Ramat Pinkas

$$\text{contour value} = \frac{1}{2}\left(R_{\text{target-trans}} + R_{\text{target-rec}} - b\right)$$

$$\text{baseline}: b = R_{\text{trans-rec}}$$



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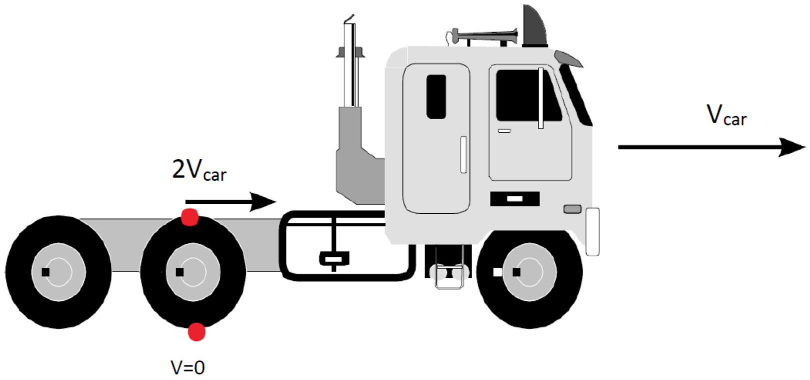

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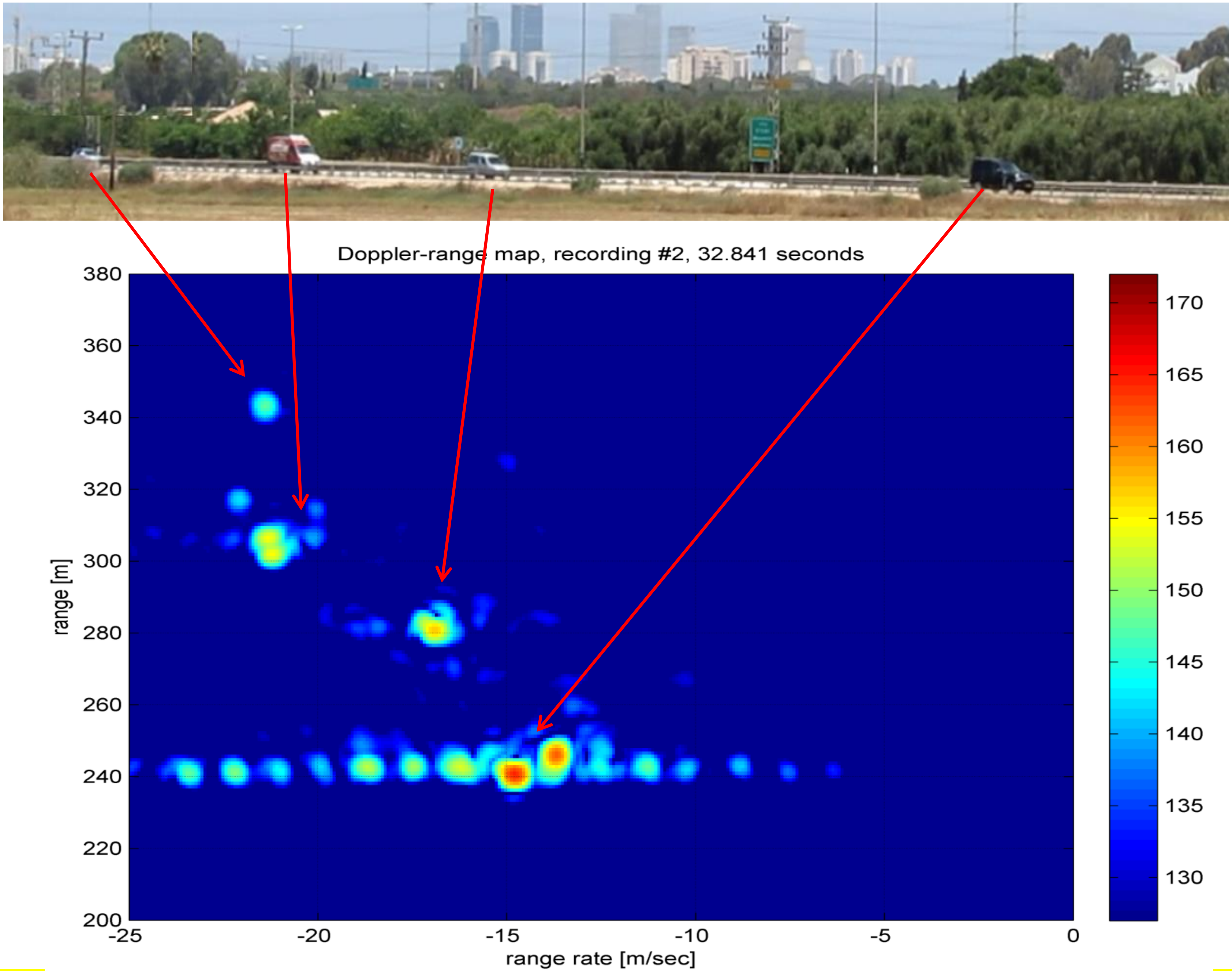

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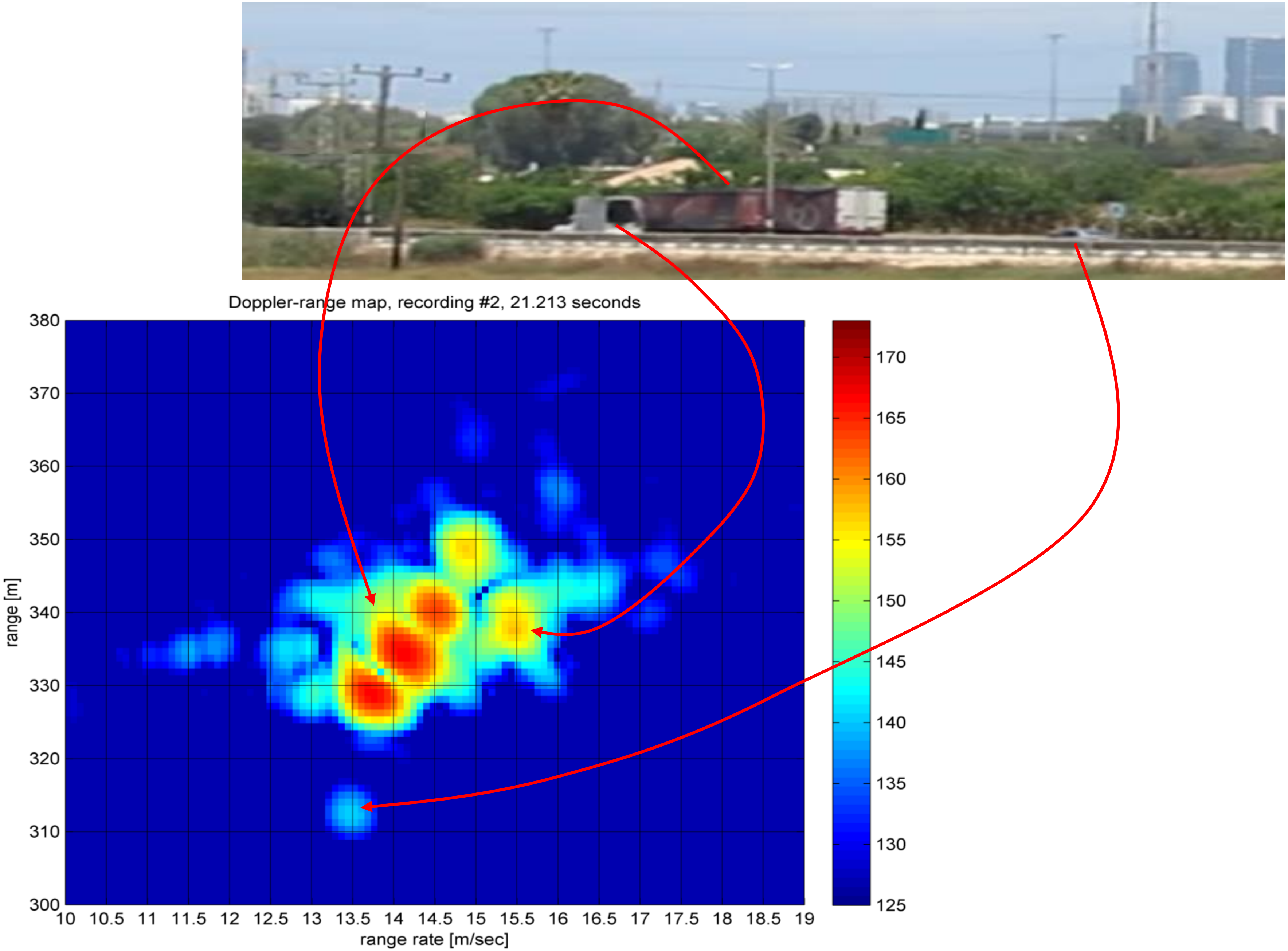
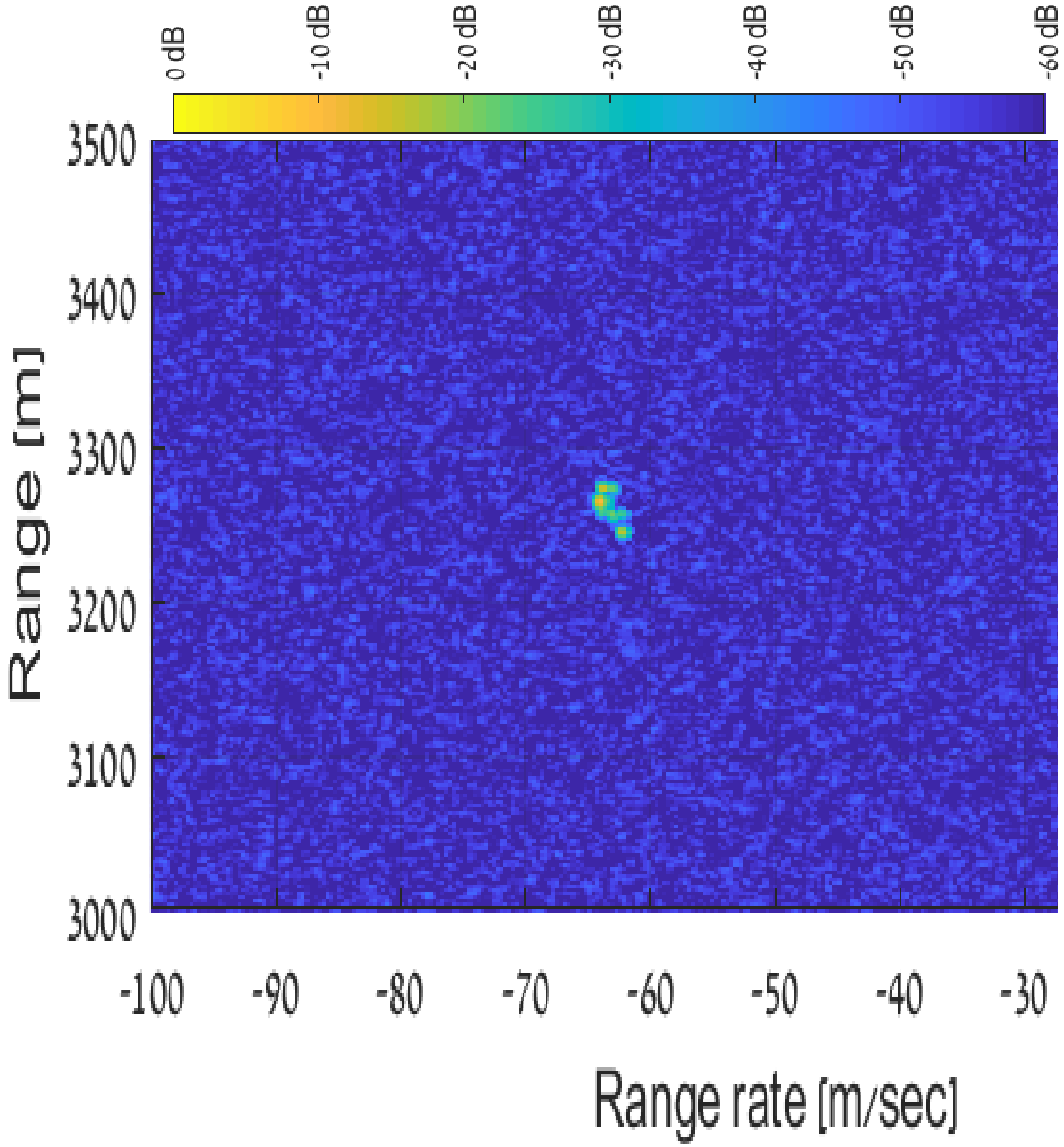
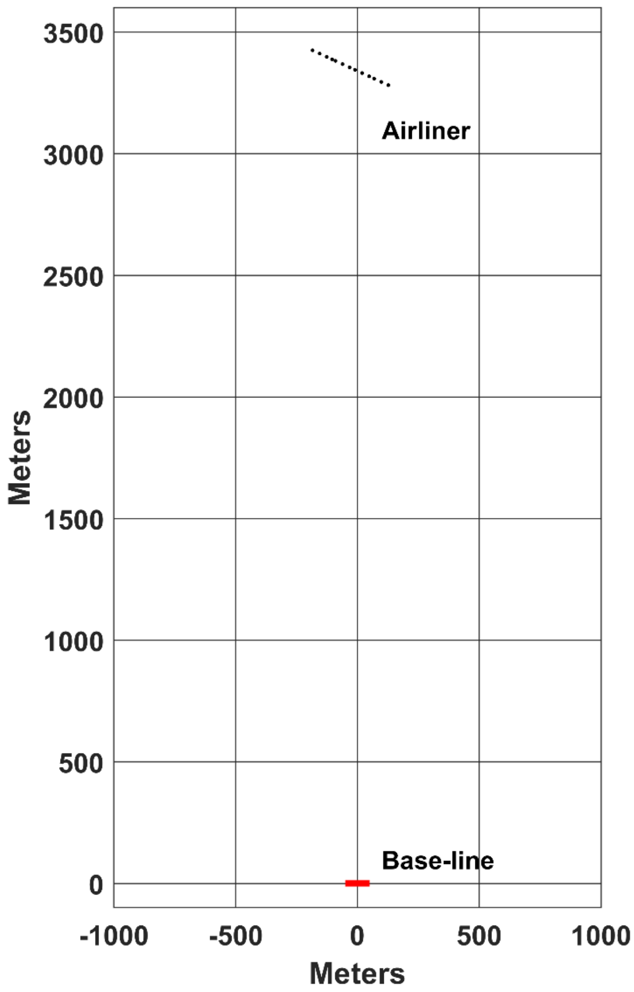
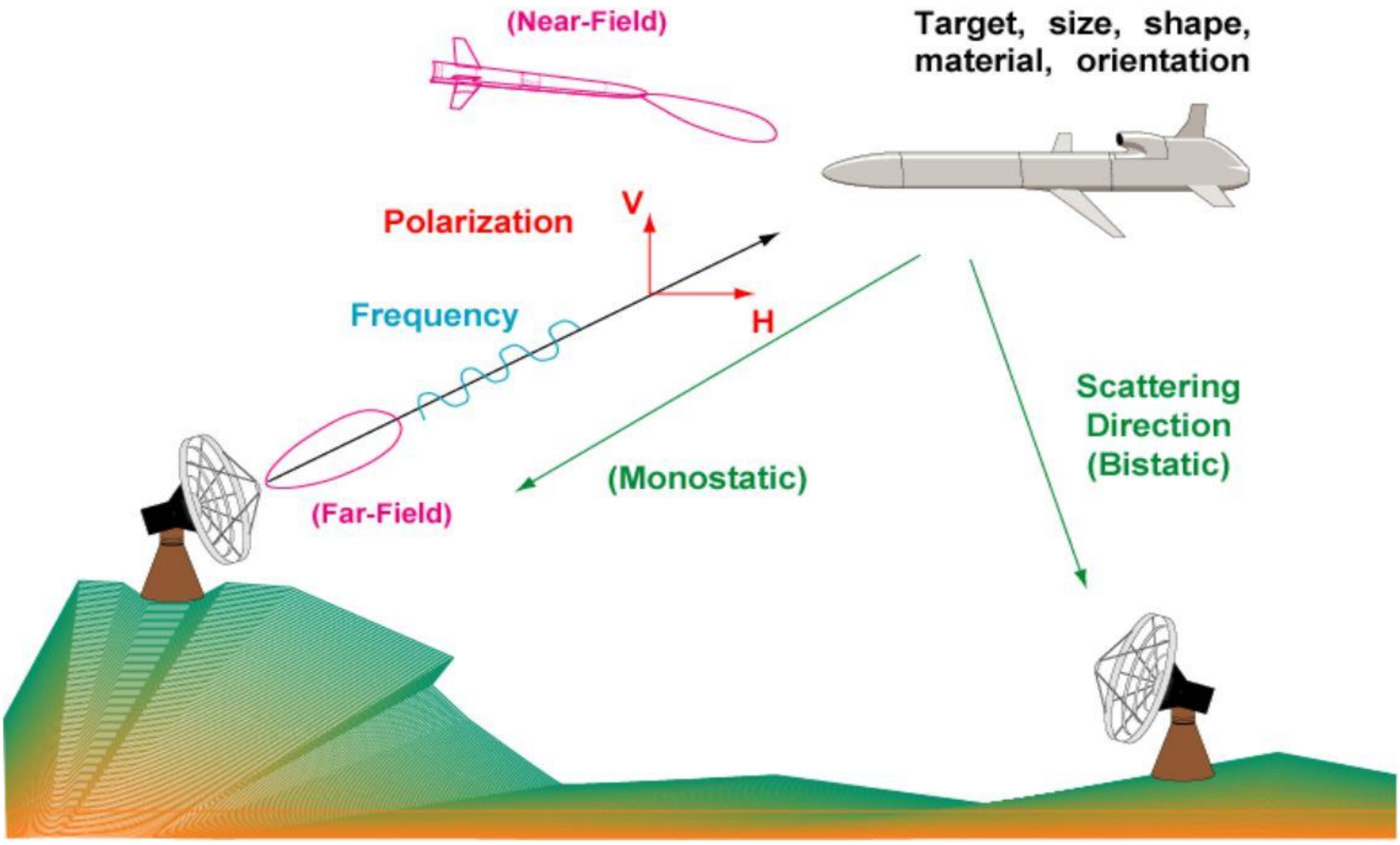


Airliner detection at 3.3 km

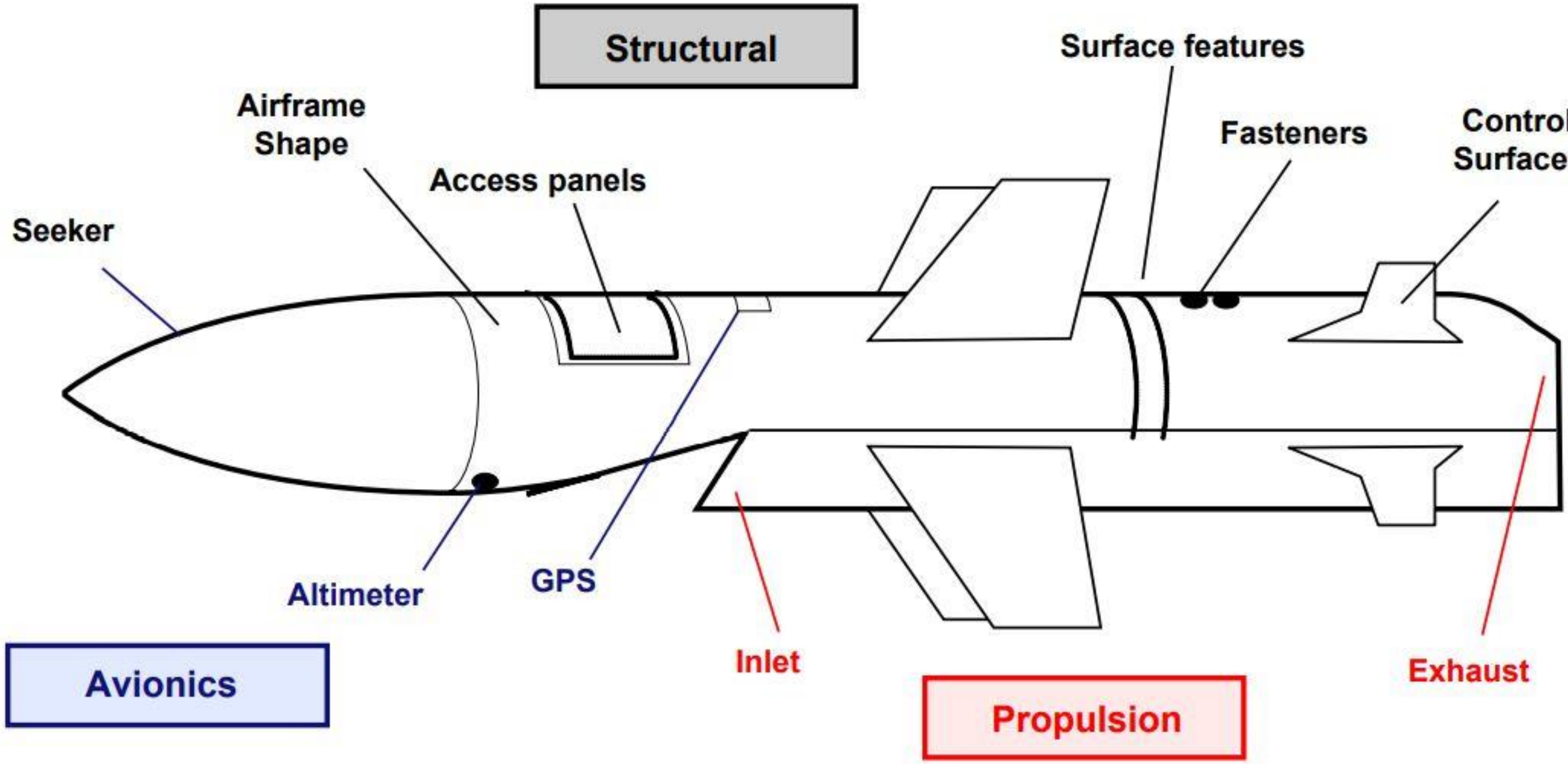




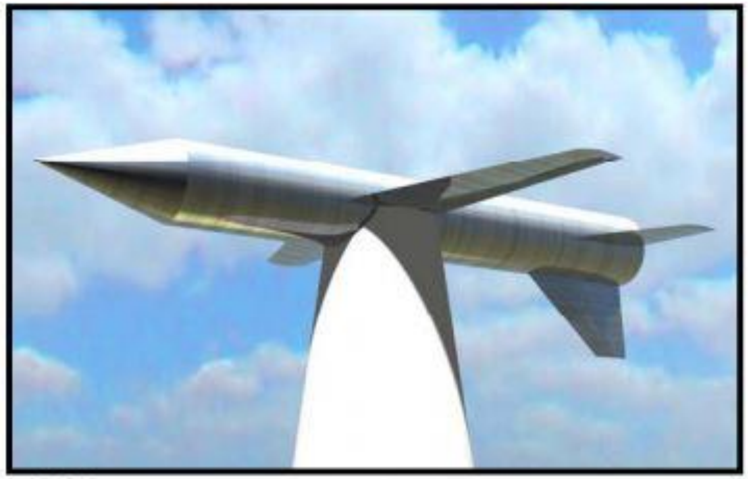
Factors Determining RCS

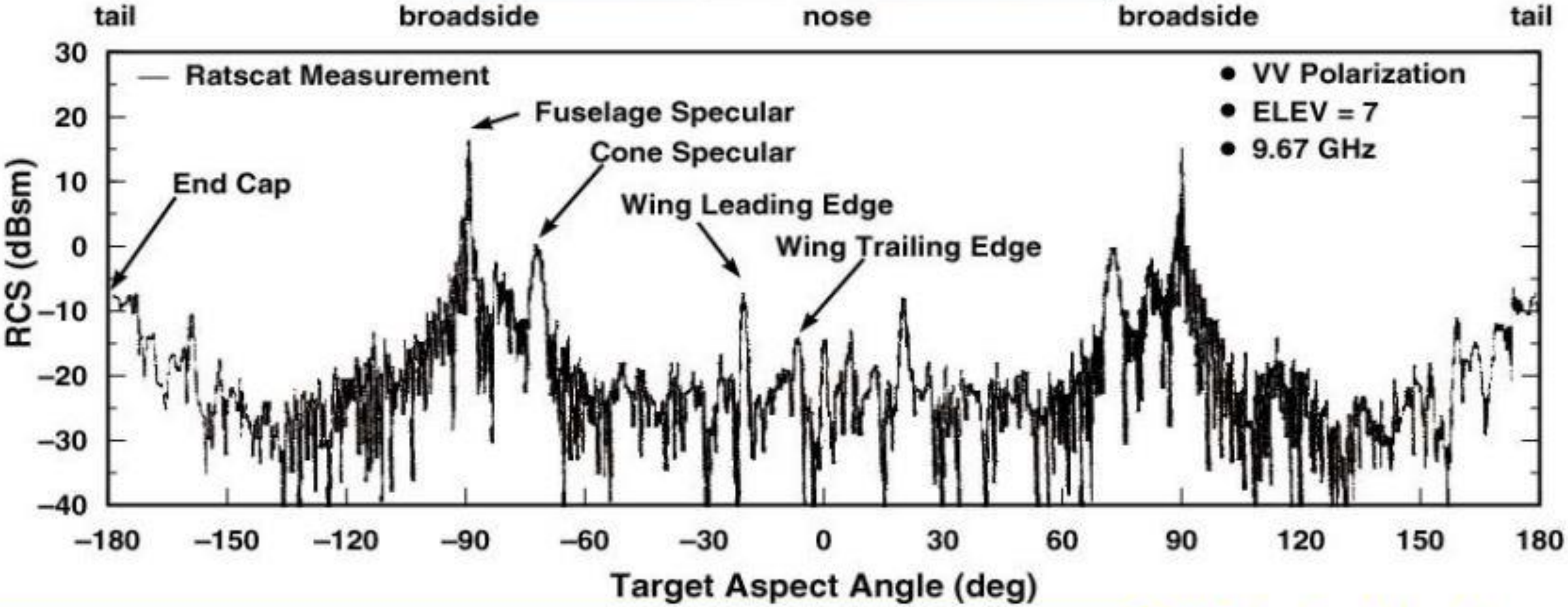


Components of Target RCS



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





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