Radar

an introduction

What is a radar?

- **RADAR**: **RA**dio **D**etection **A**nd **R**anging
- active sensor
  - radiates EM energy
  - receives the backscattered wave from a generic target
  - uses backscattered wave to detect, locate and possibly also analyze a non-cooperating target

Different types of radar/platform

- Ground-based: Air Traffic Control, detection and tracking of targets, ground-based SAR, Ground Penetrating Radar, weather radar

- Airborne: detection and tracking, surface remote sensing, radioaltimetry, weather radar

- Seaborne: target/obstacle detection and tracking

- Spaceborne: Earth Observation

Brief history of RADAR

- The first experiments by Hertz on a hill to prove the existence of EM waves date back to 1886.
- At the beginning of the new century the first experiments to detect the presence of vessels using EM waves were made.
- In the '20s the first prototypes appeared, and radar pulses were used for the remote detection of large objects.
- During the Second World War round radar screen (PPI) appeared.
- In the '60s radar technology became public domain.
- 1978: SEASAT, the first satellite radar for civilian applications.

Operation modes

- Pulsed radar:
  - the transmitted wave consists of a pulse
  - both single-antenna and two-antennas configurations possible
  - detection and distance measure possible

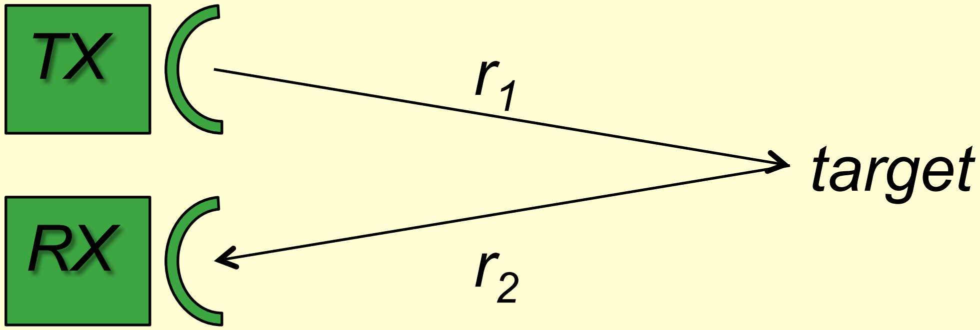
- Continuous wave radar (CW):
  - a wave is continuously transmitted
  - a single antenna is not sufficient
  - detection possible
  - distance measure possible if the wave is opportunely modulated

Antenna configuration

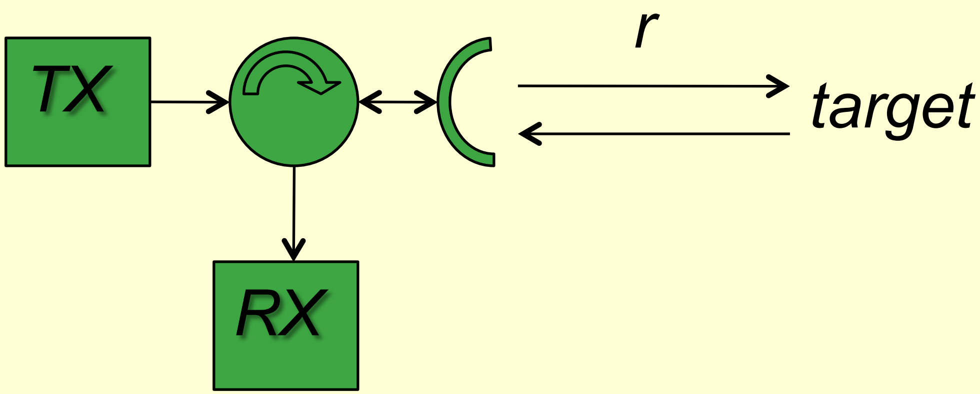
- Bistatic:
  - Transmitting (TX) antenna + receiving (RX) antenna apart
- Monostatic:
  - a single antenna is both transmitting (TX) and receiving (RX)
  - at any given time the antenna is either TX or RX (or switching)
- In this course we will deal with pulsed monostatic radar, briefly touching on bistatic (ex. interferometry)

Antenna configuration

- Bistatic:



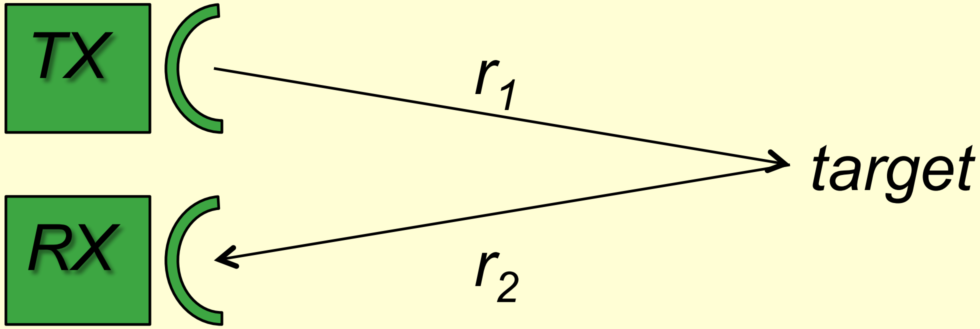
- Monostatic:



Distance measurement

- Bistatic:

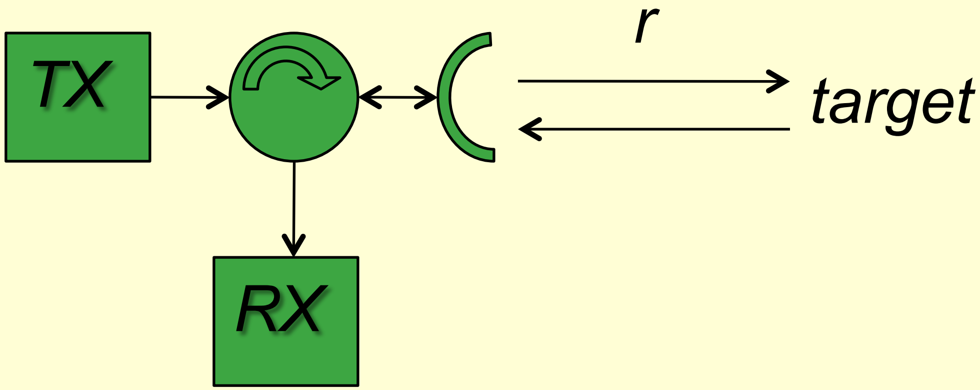
$$\Delta t = (r_1 + r_2) \cdot c$$



- Monostatic:

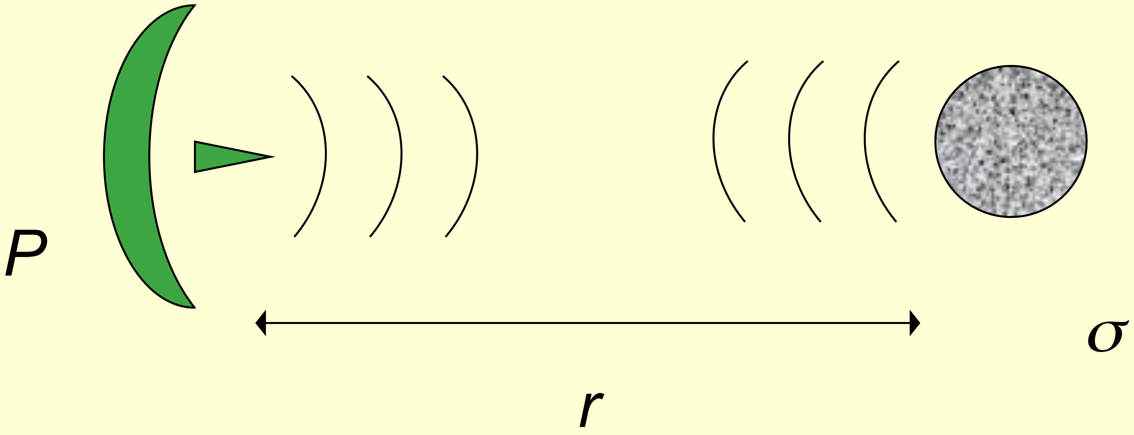
$$\Delta t = (r + r) \cdot c =$$

$$= 2 \cdot r \cdot c$$



Intensity measurement

- Classical radar configuration:



Backscattered power:

$$|\rho| \propto P \cdot \frac{\sigma}{r^4}$$

About intensity: the RADAR equation

$$P_r = \frac{G^2 \lambda^2 P_t \sigma}{(4\pi)^3 R^4}$$

system characteristics

geometry

target characteristics

- P_r = antenna-received power;
- P_t = antenna-emitted power;
- λ = operational wavelenght;
- σ = “radar cross section” of the observed target
- R = sensor-target distance (TX ≡ RX)
- G = antenna gain (TX ≡ RX)

Radar bands (IEEE standard)

Band	Frequency (GHz)
HF	0.003 - 0.03
VHF	0.03 – 0.3
UHF	0.3 - 1
L	1 - 2
S	2 - 4
C	4 - 8
X	8 - 12
Ku	12 - 18
K	18 - 27
Ka	27 – 40
V	40 - 75
W	75 - 110
mm	110 - 300

"IEEE Standard Letter Designations for Radar-Frequency Bands," IEEE Std 521-2002 (Revision of IEEE Std 521-1984) , vol., no., pp.0_1-3, 2003 doi: 10.1109/IEEESTD.2003.94224

URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1160089&isnumber=26011

Radar bands

- HF (Short waves):
  - early radar; nowadays used for over-the-horizon (OTH) radar thanks to ionospheric propagation
- VHF, UHF:
  - easy to generate great transmitting power → long range
  - ineffectiveness of stealthing techniques (large radar cross section)
  - all-weather
- L-Band
  - Moving Target Indication (MTI)

Radar bands

- S-band
  - better angle resolution
  - surveillance radar (long-range) weather radar
  - some attenuation in case of rain

- C-band
  - smaller, lighter devices (wrt S-band)
  - better resolution (wrt S-band)
  - acceptable attenuation in case of rain
  - weather radar
  - spaceborne Earth Observation

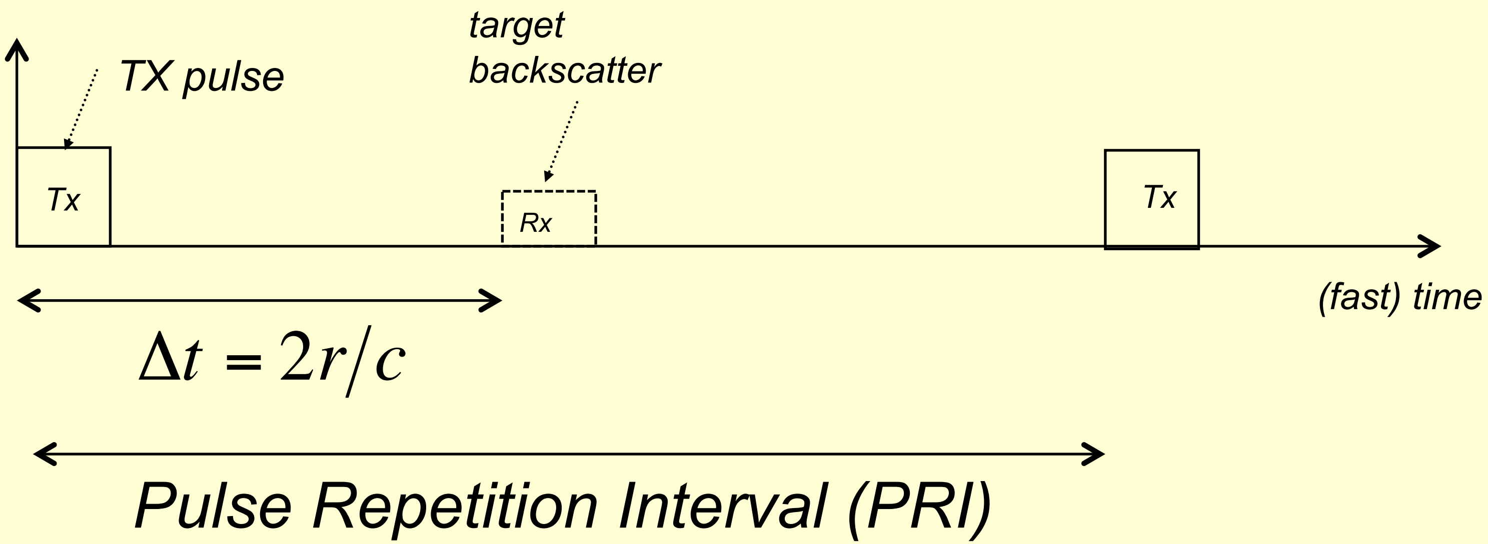
Radar bands

- X-band
  - high resolution, small and light devices
  - significant attenuation in case of rain – not really all-weather
  - short-range surveillance, Earth Observation

- K bands
  - very high resolution in principle
  - very short range due to rain and path attenuation
  - local surveillance

- mm bands
  - difficult to use due to high attenuation

Distance measurement

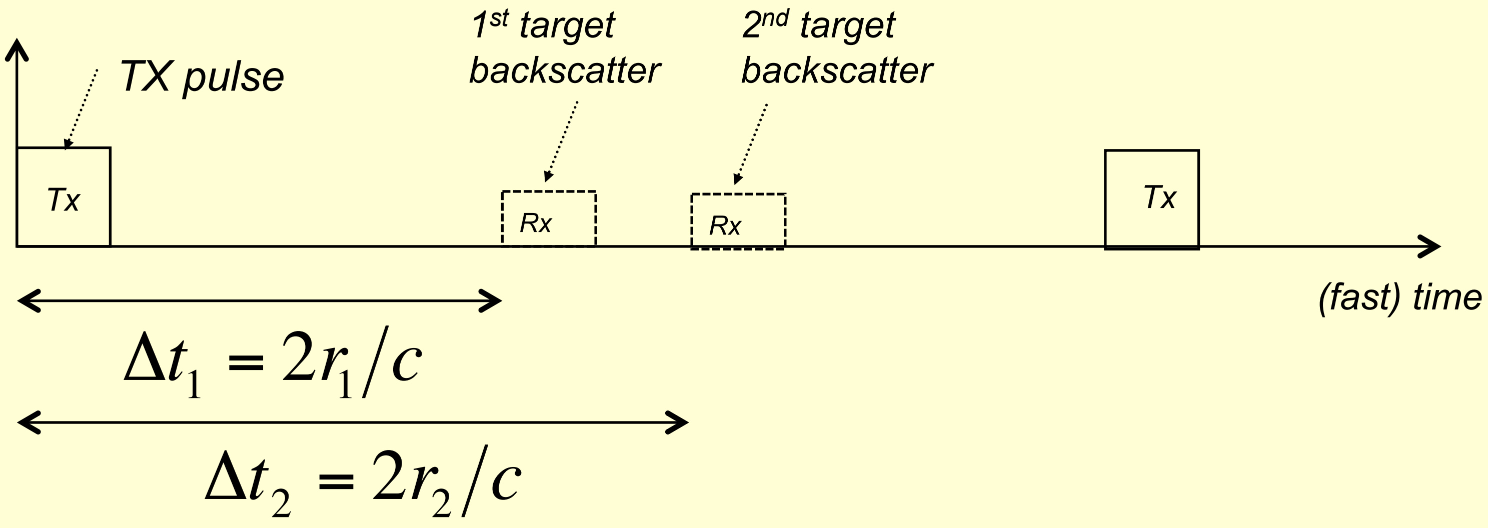


$$\Delta t = 2r/c$$

Pulse Repetition Interval (PRI)

- Presence of backscatter → target detection
- Time-delay of backscatter → target (range) location
- Propagation at speed of light → $1\mu s \approx 150$ m

Range resolution



$$\Delta t_1 = 2r_1/c$$

$$\Delta t_2 = 2r_2/c$$

- More than one target may backscatter the EM wave
- Can we tell there are two targets instead of one?

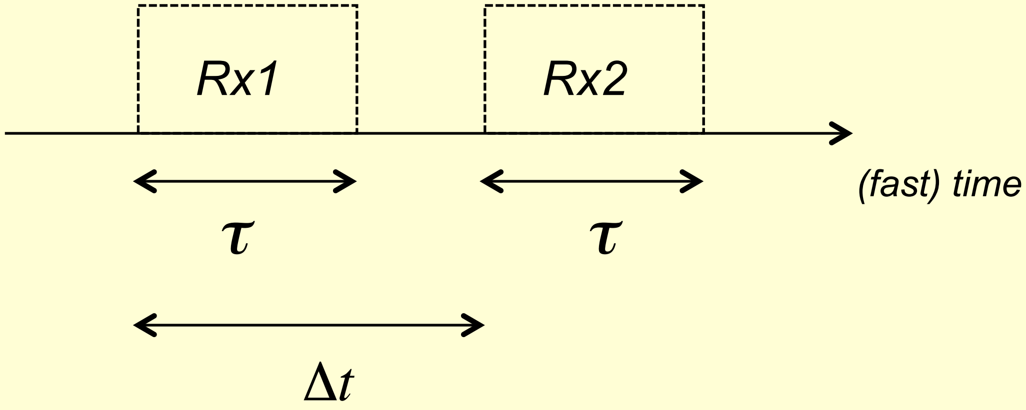
Separate detection

- Separate detection is possible as far as the two Rx pulses do not overlap:

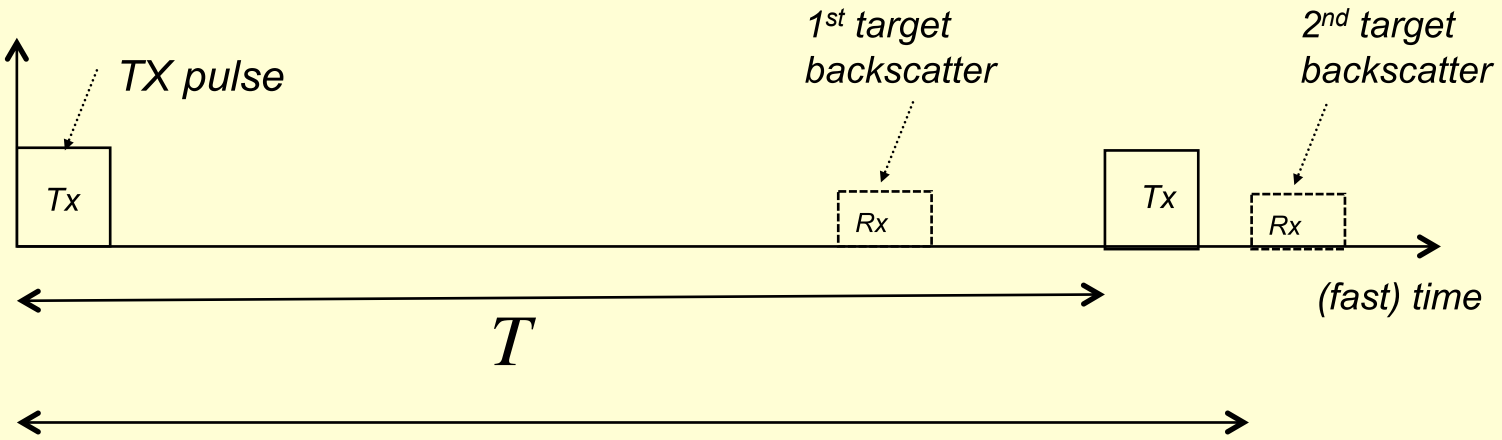
$$\Delta t = \Delta t_2 - \Delta t_1 = \frac{2r_2}{c} - \frac{2r_1}{c} = \frac{2\Delta r}{c} \geq \tau$$

- Range resolution:

$$\delta_r = \frac{c\tau}{2}$$



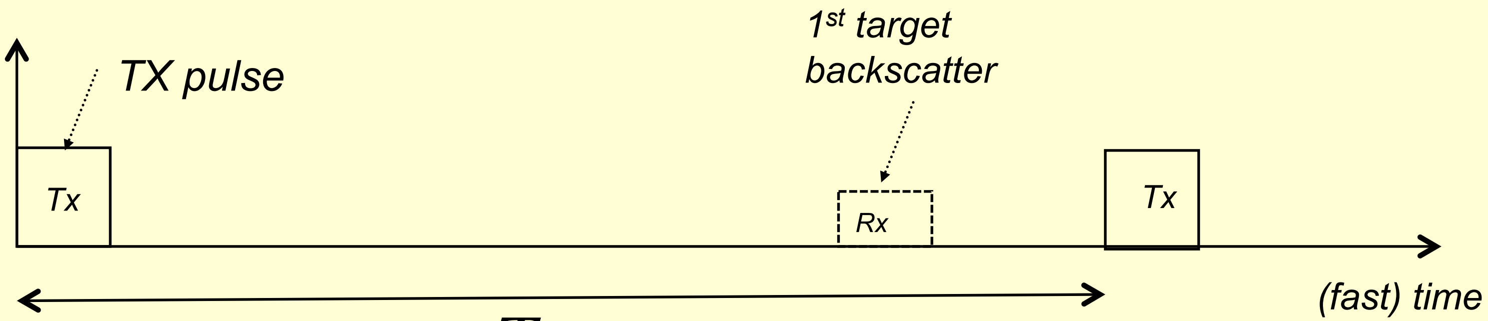
Max non-ambiguous range



$$\Delta t_2 = 2r_2/c \rightarrow \Delta t_{apparent} = \Delta t_2 - T$$

- the second target is apparently very close to the radar but actually farther than the *non-ambiguous range!*

Max non-ambiguous range



T =

max non–ambiguous response time

- Maximum range:

$$R_{n-a} = \frac{cT}{2}$$

Angle resolution

- Recall: antenna directivity (D) and gain (G)

$$D = \frac{\max radiation\ intensity}{mean\ radiation\ intensity} = \frac{\max \frac{P_r}{solid\ angle}}{\frac{P_{tot}^{out}}{4\pi}}$$

$$G = \frac{\max radiation\ intensity}{mean\ lossless\ radiation\ intensity} = \frac{\max \frac{P_r}{solid\ angle}}{\frac{P_{tot}^{in}}{4\pi}}$$

- antenna radiating efficiency, accounting for losses:

$$G(\phi,\vartheta) = \rho_r \cdot D(\phi,\vartheta)$$

Radiation pattern

$G(\phi,\vartheta)$

$D(\phi,\vartheta)$

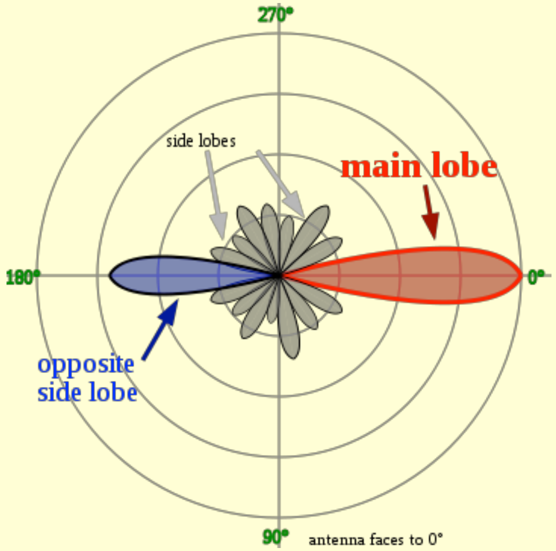
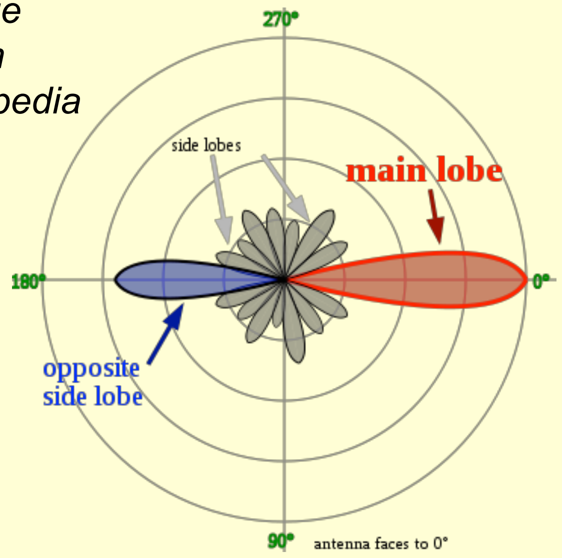


image from Wikipedia

- Both directivity and gain pattern are defined as functions of azimuth (ϕ) and elevation (ϑ)
- a "main lobe" can generally be pinpointed

Beam aperture

image from Wikipedia



$\phi_A \approx \lambda / L_\phi$: L_ϕ antenna azimuth size

$\theta_A \approx \lambda / L_\theta$: L_θ antenna elevation size

- Beam aperture generally defined based on -3 dB radiation intensity with respect to boresight

Effective area

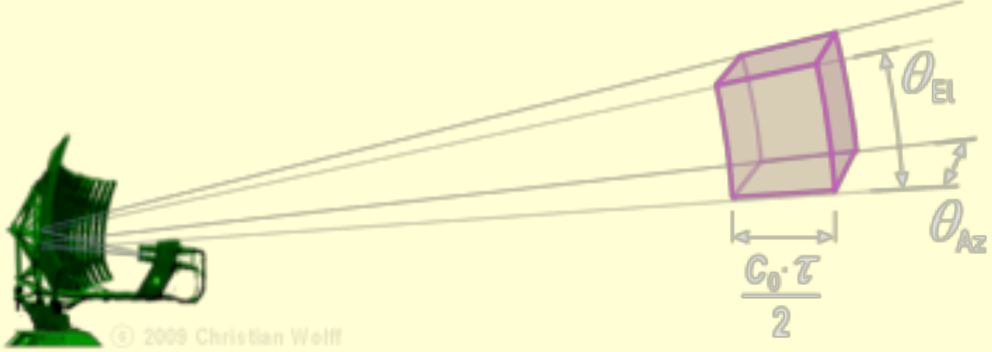
- Equivalent area shown by a receiving antenna:

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \rho_a A_g}{\lambda^2}$$

- A_e: effective area;
- A_g: geometric area;
- ρ_a: aperture efficiency.

Cell resolution

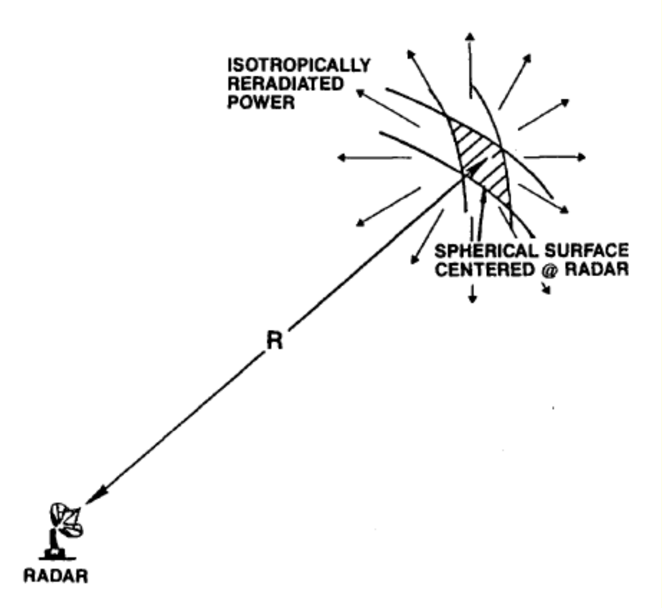
http://www.radartutorial.eu/01.basics/rb20.en.html



- In the usual assumption, volume resolution determined by:
  - aperture angle θ_{el} , θ_{az} (-3 dB angle) of the antenna beam
  - range resolution $\delta = c\tau/2$

Radar Cross Section (RCS)

$$S = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

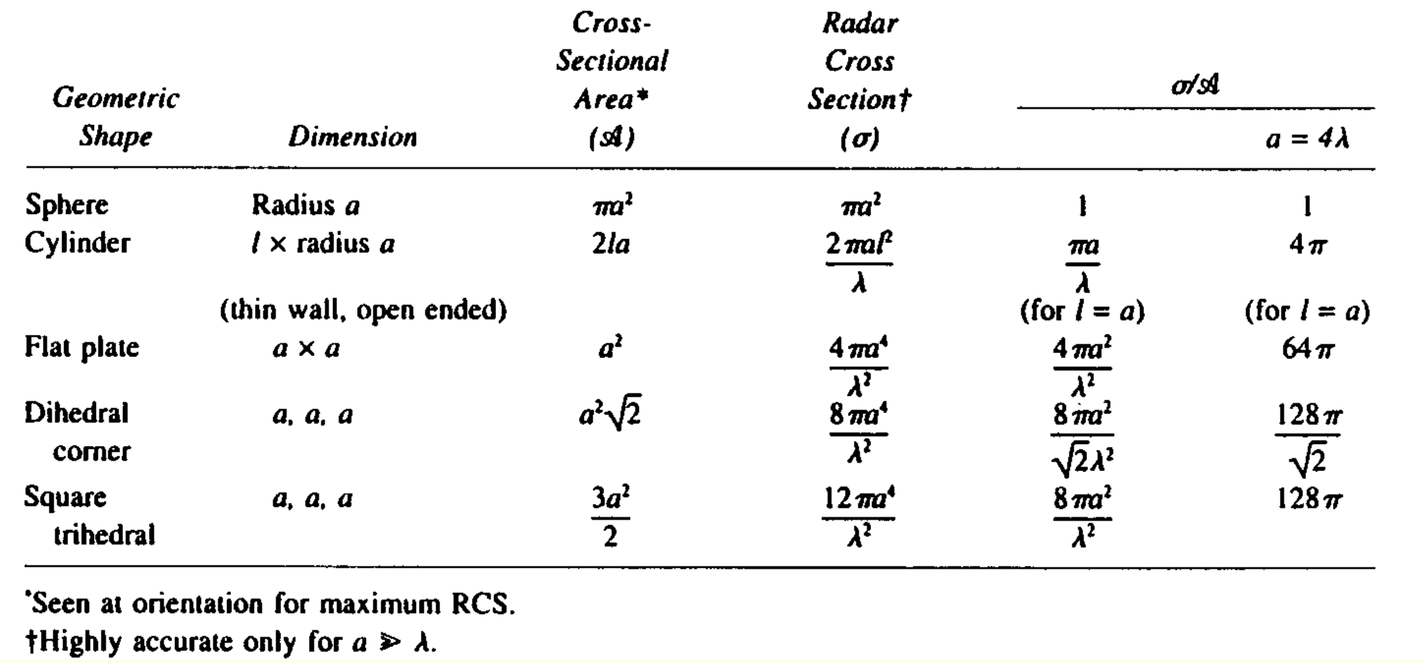


- σ [m^2]= RCS: superficie equivalente della sfera che riflette verso il radar la stessa quantità di potenza riflessa dal bersaglio.

RCS estimate

- RCS complex to estimate, varying with many factors
- Single, large target:
  - sum of independent small targets
  - each target contribute can be approximated as a response from a basic geometric shape
  - “small” targets never exceed a few λs

RCS for basic geometric shapes



Geometric Shape	Dimension	Cross-Sectional Area* ($\mathcal{A}$)	Radar Cross Section† (σ)	$\sigma/\mathcal{A}$	
					$a = 4\lambda$
Sphere	Radius a	πa^2	πa^2	1	1
Cylinder	$l \times$ radius a (thin wall, open ended)	$2la$	$\frac{2\pi a l^2}{\lambda}$	$\frac{\pi a}{\lambda}$ (for $l = a$)	4π (for $l = a$)
Flat plate	$a \times a$	a^2	$\frac{4\pi a^4}{\lambda^2}$	$\frac{4\pi a^2}{\lambda^2}$	64π
Dihedral corner	a, a, a	$a^2\sqrt{2}$	$\frac{8\pi a^4}{\lambda^2}$	$\frac{8\pi a^2}{\sqrt{2}\lambda^2}$	$\frac{128\pi}{\sqrt{2}}$
Square trihedral	a, a, a	$\frac{3a^2}{2}$	$\frac{12\pi a^4}{\lambda^2}$	$\frac{8\pi a^2}{\lambda^2}$	128π

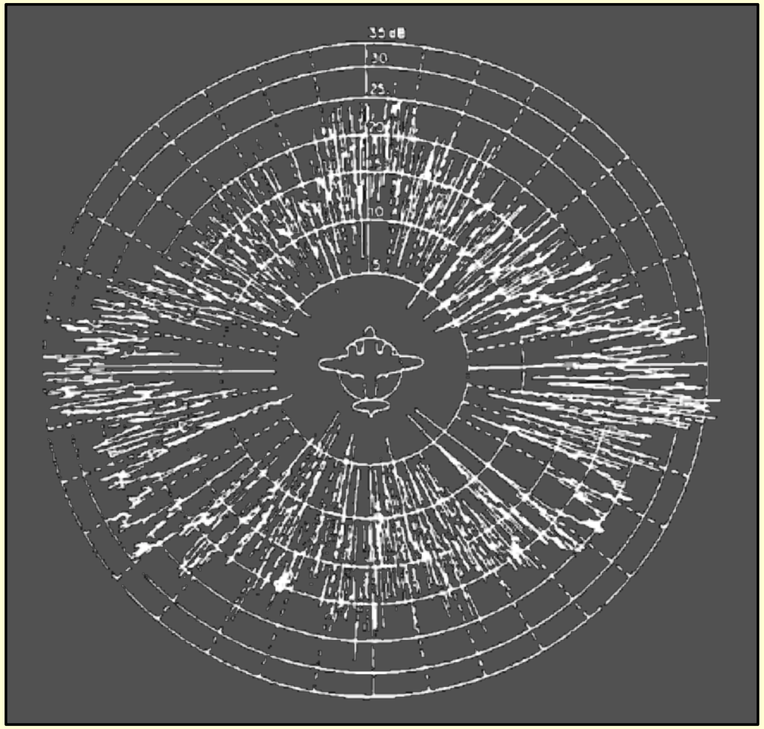
*Seen at orientation for maximum RCS.

†Highly accurate only for $a \gg \lambda$.

- Sphere has:
  - minimum RCS
  - λ-independent RCS $(a >> \lambda)$

RCS of a real target

- Very complex to estimate, too many elementary reflectors interacting - usually measured directly
- Example: experimental RCS of B-26 aircraft vs. azimuth angle at 3 GHz frequency



http://www.radartutorial.eu/18.explanations/ex09.en.html

From Skolnik, “Radar Handbook”