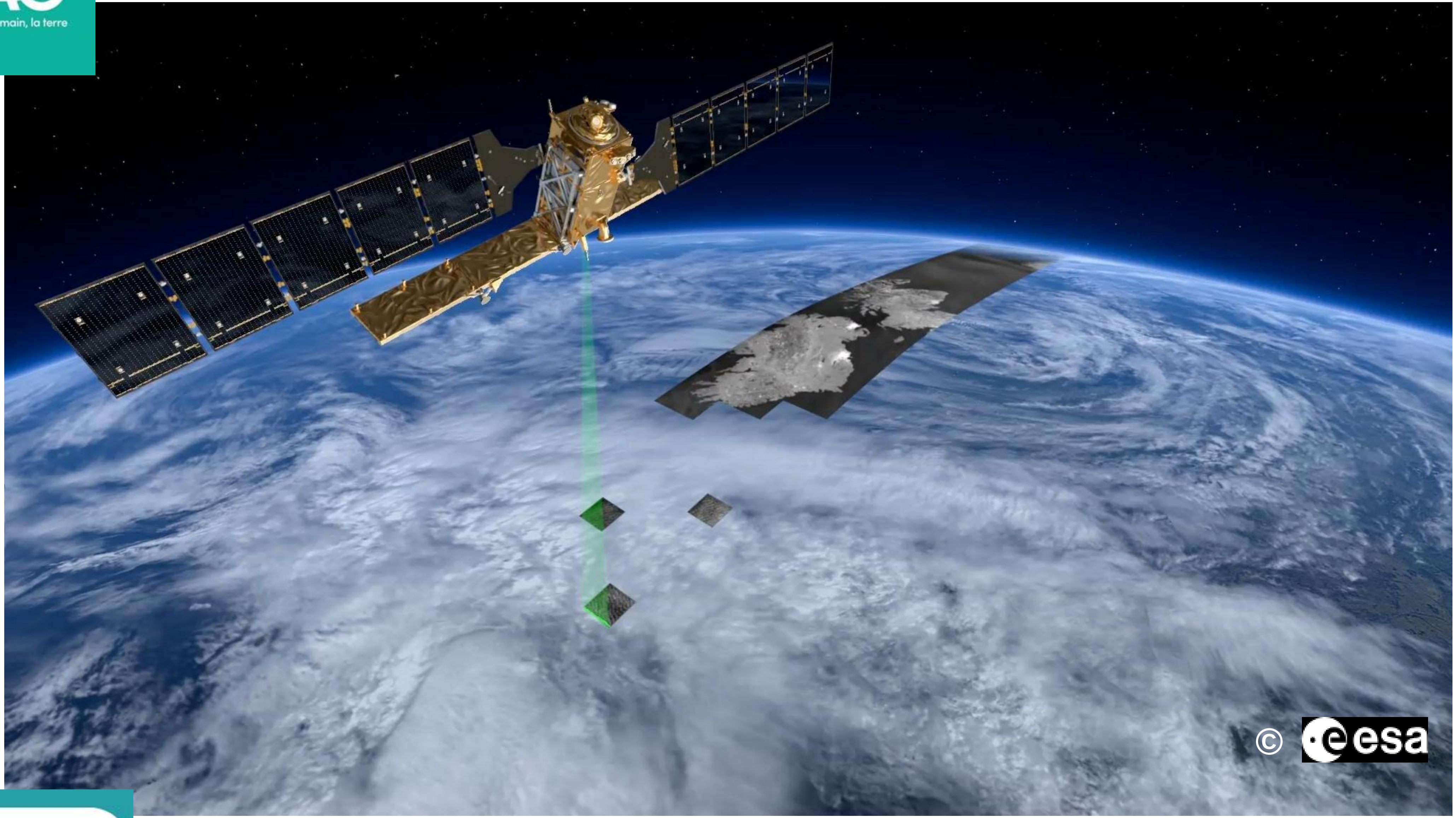
Radar remote sensing



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Outline

- ❖ **Introduction**
- ❖ **Radar types**
- ❖ **Radar waves propagation**
- ❖ **Radar cross-section**
- ❖ **Radar range equation**

Introduction

What is RADAR?

- **RADAR : Radio Detection and Ranging**
- Radio $\Rightarrow$ Electromagnetic radiation (EMR)
- Detection $\Rightarrow$ Targets
- And $\Rightarrow$ Simultaneously
- Ranging $\Rightarrow$ 4D localization
- **Sensors used to warn and measure/monitor**
- **Important parameters**
- Precision, uncertainty, resolution
- Volume monitored, rate

History

- **1864:** James Clerk Maxwell : EM laws
- **1889:** Heinrich Rudolf Hertz: EMR reflected by metal surfaces
- **Early XXth century**

- Invention of radio (Marconi) $\Rightarrow$ development of antennas
- 1904: Telemboliskop patent $\Rightarrow$ possibility to detect ships in a very dense fog (RAD)
- 1920s: detection experiments using antennas
- 1934: Experiments on “radars” (λ = 60 – 80 cm). Patent from CSF (France)
- 1935: Patent from Robert Watson Watt. Birth of the radar. UK instaledl first net of radars

History

- ❖ **WWII:** Radar as we know it (more or less)

- ➢ Development of airborne radars ⇒ night fightngs and bombings

- ➢ Experiments on polarization: presence of “noise” due to rain, snow, …
  ⇒ development of meteorological radars after WWII
  ⇒ techniques of scrambling and counter-measures

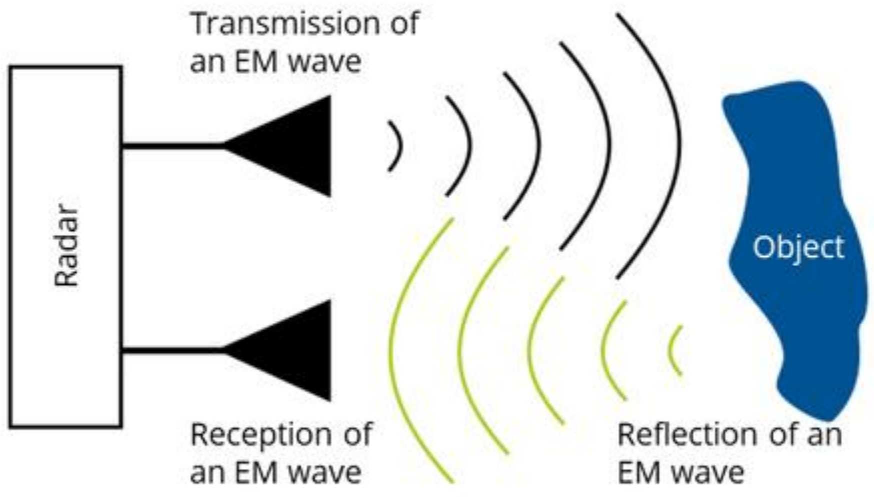
- ❖ **Since then:** radar widely used in meteorology, astrometry, … as well as for monitoring planes and cars

- ❖ **1950s**: Invention of Synthetic Aperture Radar (SAR) ⇒ high resolution (HR) radar images

- ❖ **1965**: Tuckley and Cooley (re)discover the Fast Fourier transform (FFT) ⇒ reduces the number of computations from $O(N^2)$ to $O(N * \log N)$ for N samples signal ⇒ allows to work on HR images

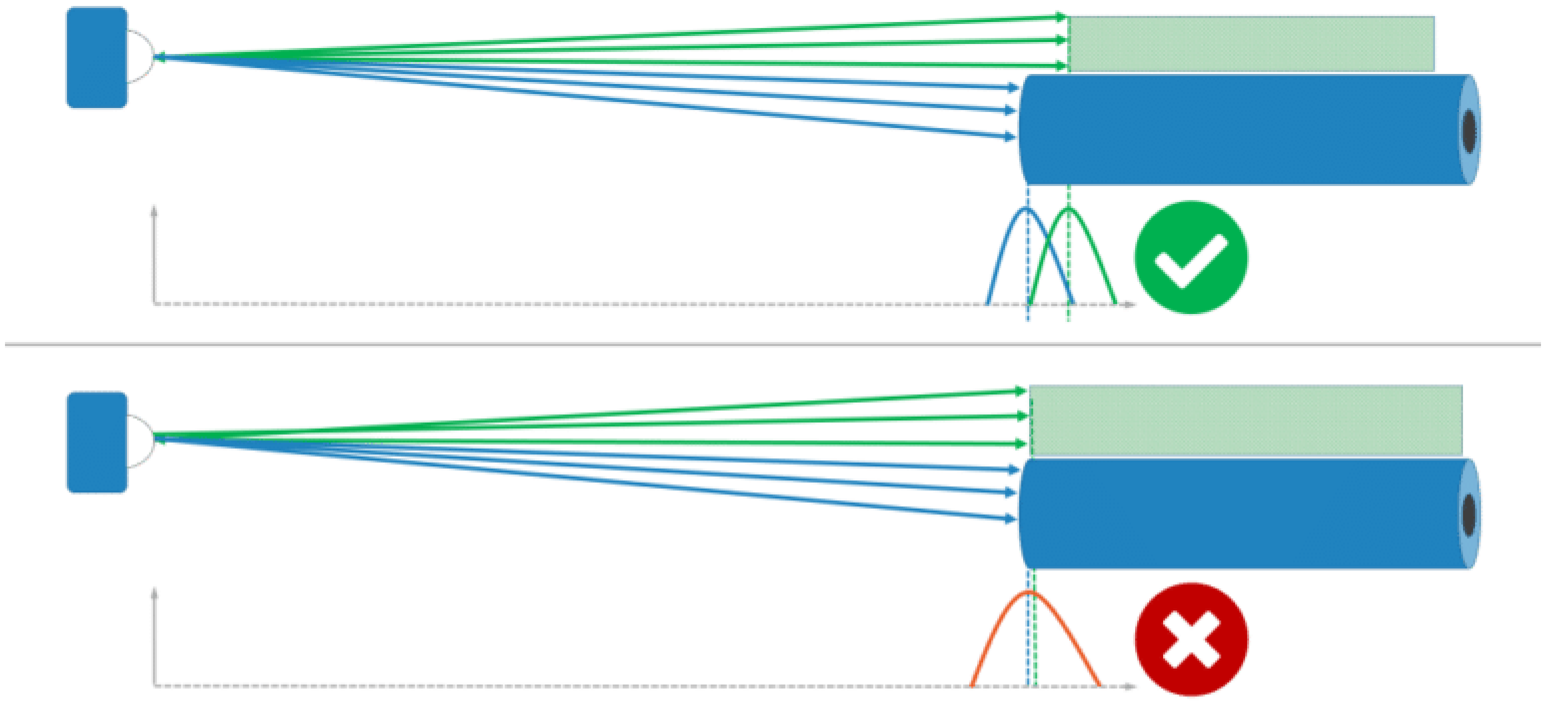
Principle

- ❖ EM waves are reflected by any significant change in the medium they go through
- ❖ Emission of a powerful EM wave transmitted by an antenna
- ❖ Signal reflected with a very small amplitude $\Rightarrow$ amplification of the received signals
- ❖ Emitted (transmitted) signal:
  - ➢ Radar emits an EM impulsion and waits for its return
  - ➢ Radar continuously
- ❖ Intensity of the received signal depends on target’s :
  - ➢ Shape
  - ➢ Nature
  - ➢ Orientation



https://www.ilmsens.com/short-range-radar/

Principle



https://ondosense.com/en/radar-know-how-optimal-use-of-radar-sensors/radar-tutorial-distance-measurement-with-radar-sensors/

Distance(time)-based discrimination
Not angular contrary to optics

Radar frequencies

Band	Frequency	Wavelength	Application
HF	3 – 30 MHz	10 – 100 m	Over-the-horizon radar, oceanographic mapping
VHF	30 – 300 MHz	1 – 10 m	Oceanographic mapping, atmospheric monitoring, long-range search
UHF	0.3 – 1 GHz	1 m – 30 cm	Long-range surveillance, foliage penetration, ground penetration, atmospheric monitoring
L	1– 2 GHz	15– 30 cm	Satellite imagery, mapping, long-range surveillance, environmental monitoring
S	2 – 4 GHz	7.5– 15 cm	Weather radar, air traffic control, surveillance, search, IFF (identify, friend or foe)
C	4– 8 GHz	3.75– 7.5 cm	Hydrological radar, topography, fire control, weather
X	8– 12 GHz	2.5– 3.75 cm	Cloud radar, air-to-air missile seeker, maritime, air turbulence, police radar, high-resolution imaging, perimeter surveillance
Ku	12– 18 GHz	1.7– 2.5 cm	Remote sensing, short-range fire control, perimeter surveillance; pronounced "kay-you"
K	12 = 8– 27 GHz	1.2– 1.7 cm	Police radar, remote sensing, perimeter surveillance
Ka	27– 40 GHz	7.5– 12 mm	Police radar, weapon guidance, remote sensing, perimeter surveillance, weapon guidance; pronounced "kay-a"
V	40– 75 GHz	4– 7.5 mm	Perimeter surveillance, remote sensing, weapon guidance
W	75 – 110 GHz	2.7 – 4 mm	Perimeter surveillance, remote sensing, weapon guidance

: IEEE radar bands and applications.

https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Electronics/Microwave_and_RF_Design_I_-_Radio_Systems_%28Steer%29/05%3A_RF_Systems/5.10%3A_Radar_Systems

Radar types

Monostatic, bistatic, multistatic

- **Monostatic radar (most typical)**

  - Transmitter and receiver have a common antenna and electronics $\Rightarrow$ less space requirement and easier synchronization between transmitter and receiver

  - Only the signal backscattered by the target is received by the antenna

- **Bistatic radar**

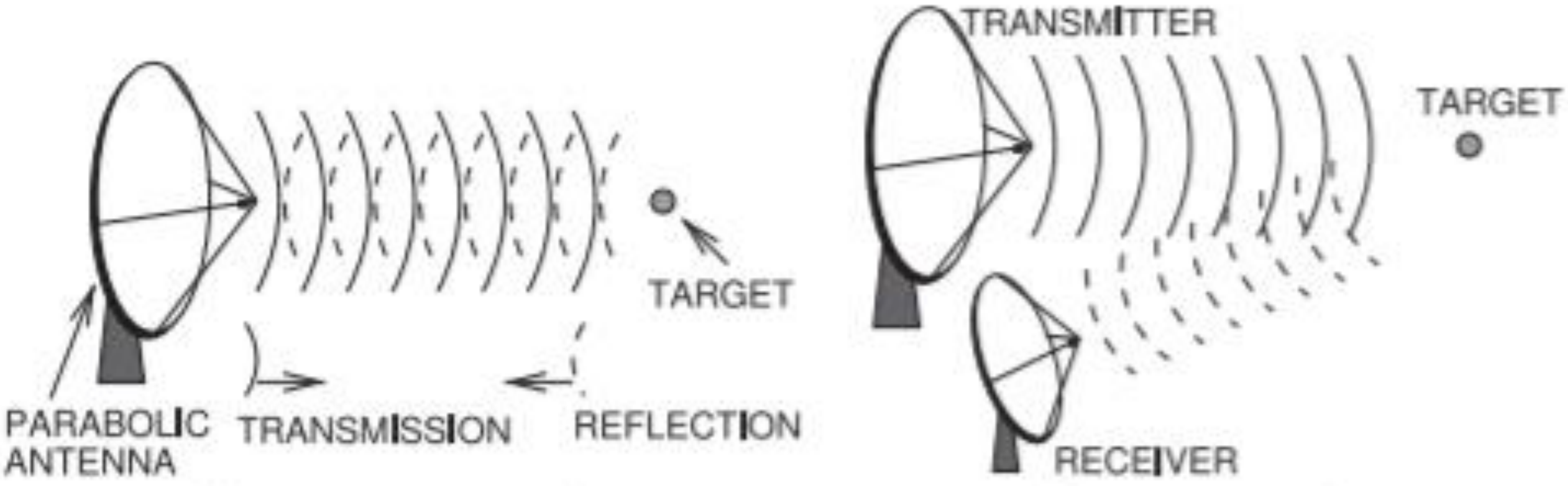
  - Opportunity to modify the locations of the transmitter and the receiver to optimize the quantity of information on the target

  - Good synchronization between transmitter and receiver required

- **Multistatic radar**

  - One transmitter, several receivers (e.g., GNSS receivers from GPS, GLONASS, Galileo … constellations)

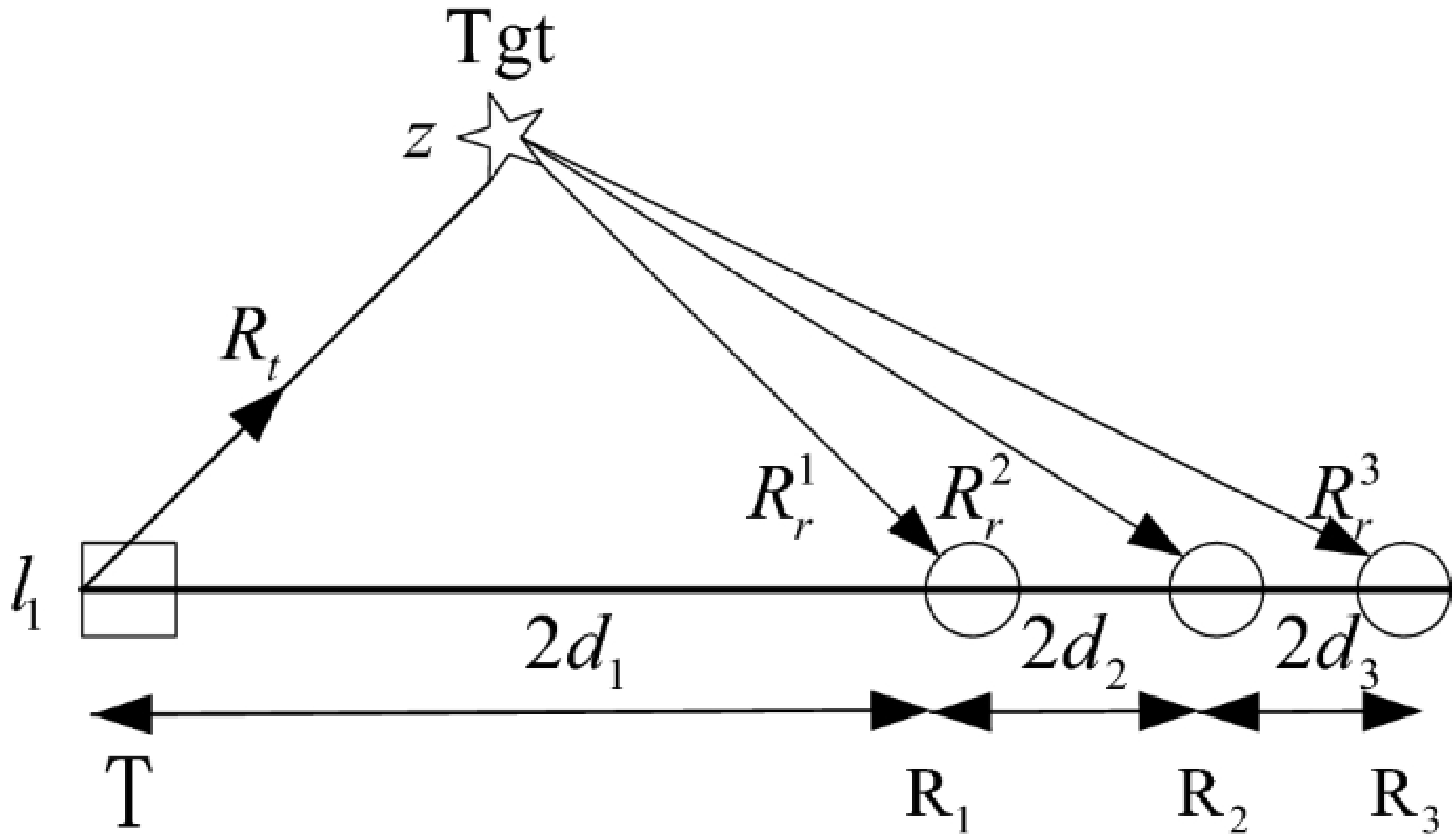
Monostatic, bistatic



(a) Monostatic radar (b) Bistatic radar

https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Electronics/Microwave_and_RF_Design_I_-_Radio_Systems_%28Steer%29/05%3A_RF_Systems/5.10%3A_Radar_Systems

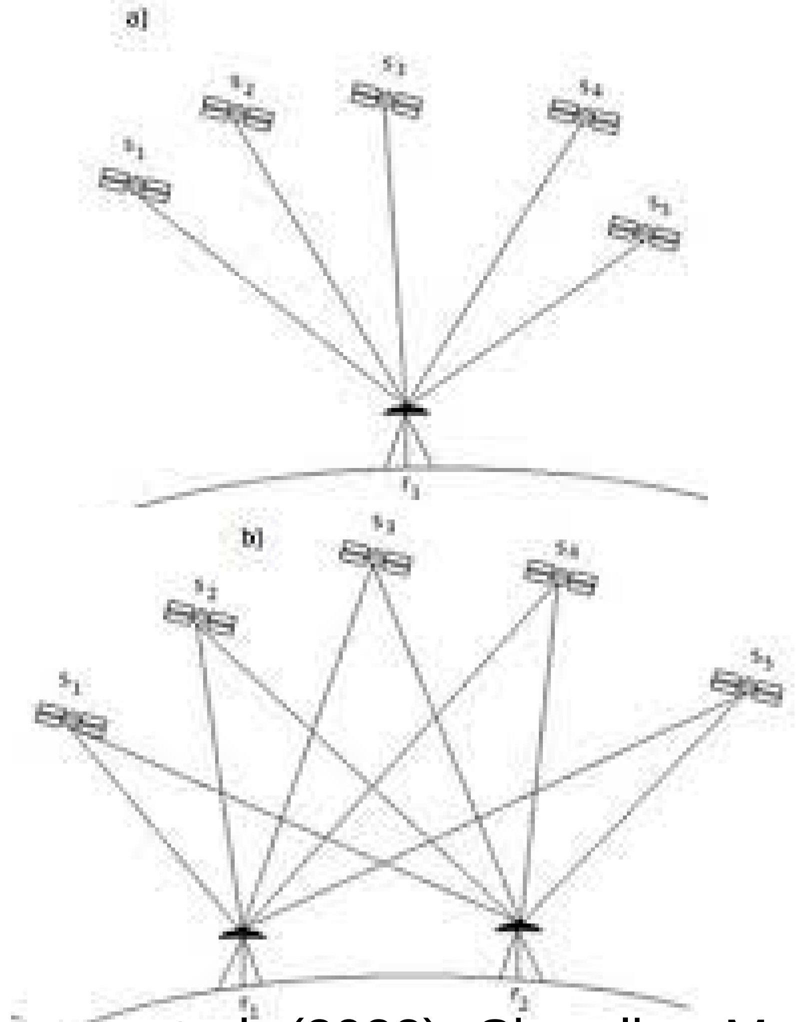
Multistatic



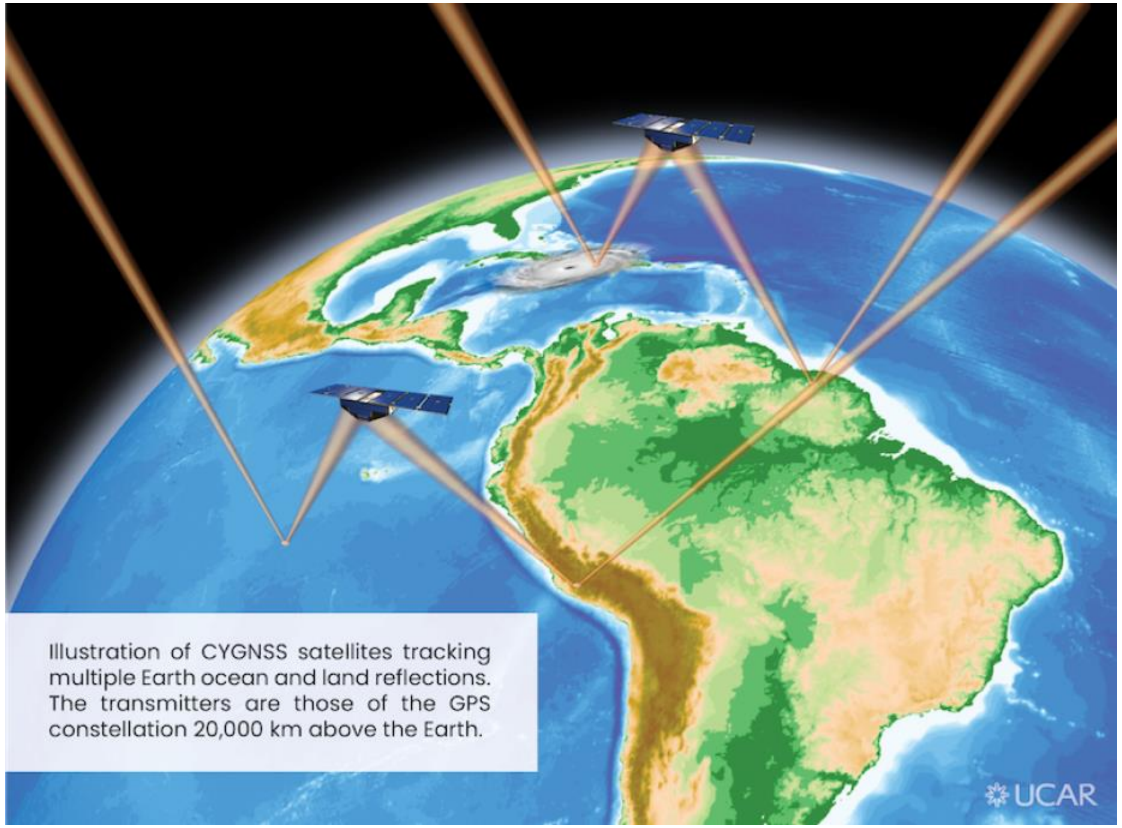
Li et al. (2022). Optimal deployment of multistatic radar for belt barrier coverage, *Wireless Networks, 28*, 2213-2235, doi: 10.1007/s11276-022-02939-5

Multistatic

GNSS for positionning



GNSS Reflectometry (GNSS-R)



https://www.cosmic.ucar.edu/global-navigation-satellite-system-gnss-background/gnss-reflectometry

Marques et al. (2022). Shoreline Monitoring by GNSS-PPP Aiming to Attendance the Law 14.258/2010 from Pernambuco State, Brazil, *Bulletin of Geodetic Sciences, 25(2)*, e2019012, doi: 10.1590/s1982-21702019000200012

Radar waves propagation

Radar waves propagation

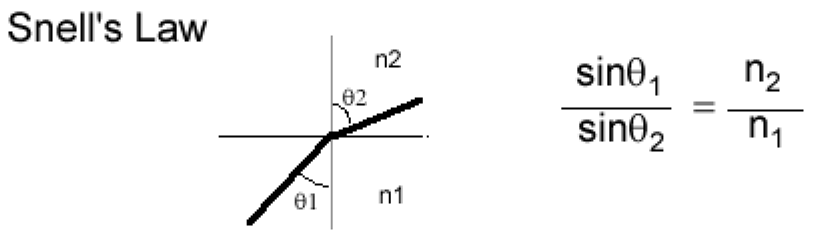
❖ **Atmosphere refraction effect**

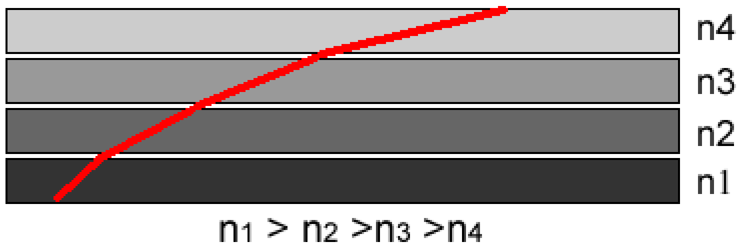
➢ Atmospheric refraction index slightly decreases with altitude

➢ This decrease is related to the diminishing of the atmosphere pressure

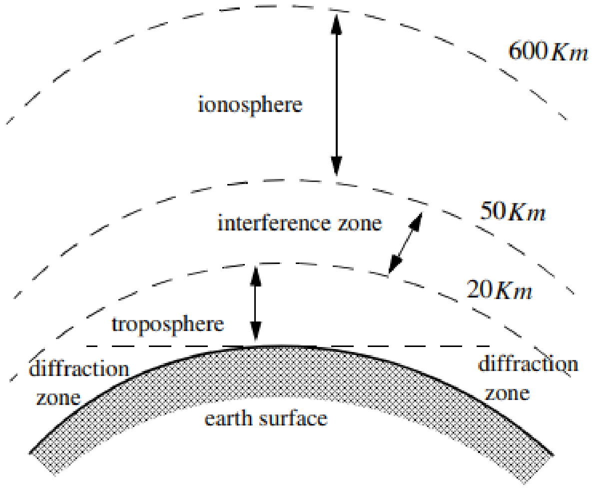
➢ The atmosphere can be described as a succession of homogenous finite layers characterized by their refraction index (n_i) decreasing as i increases. Snell-Descartes law can be applied: $n_i \sin\theta_i = n_j \sin\theta_j$

➢ It causes a slight bending of the EM wave trajectory and a delay caused by the interactions with:
- the electrons present in the ionosphere
- the "dry" gases of the troposphere (O_2, N_2, CO_2, …)
- water vapor and liquid water of the troposhere





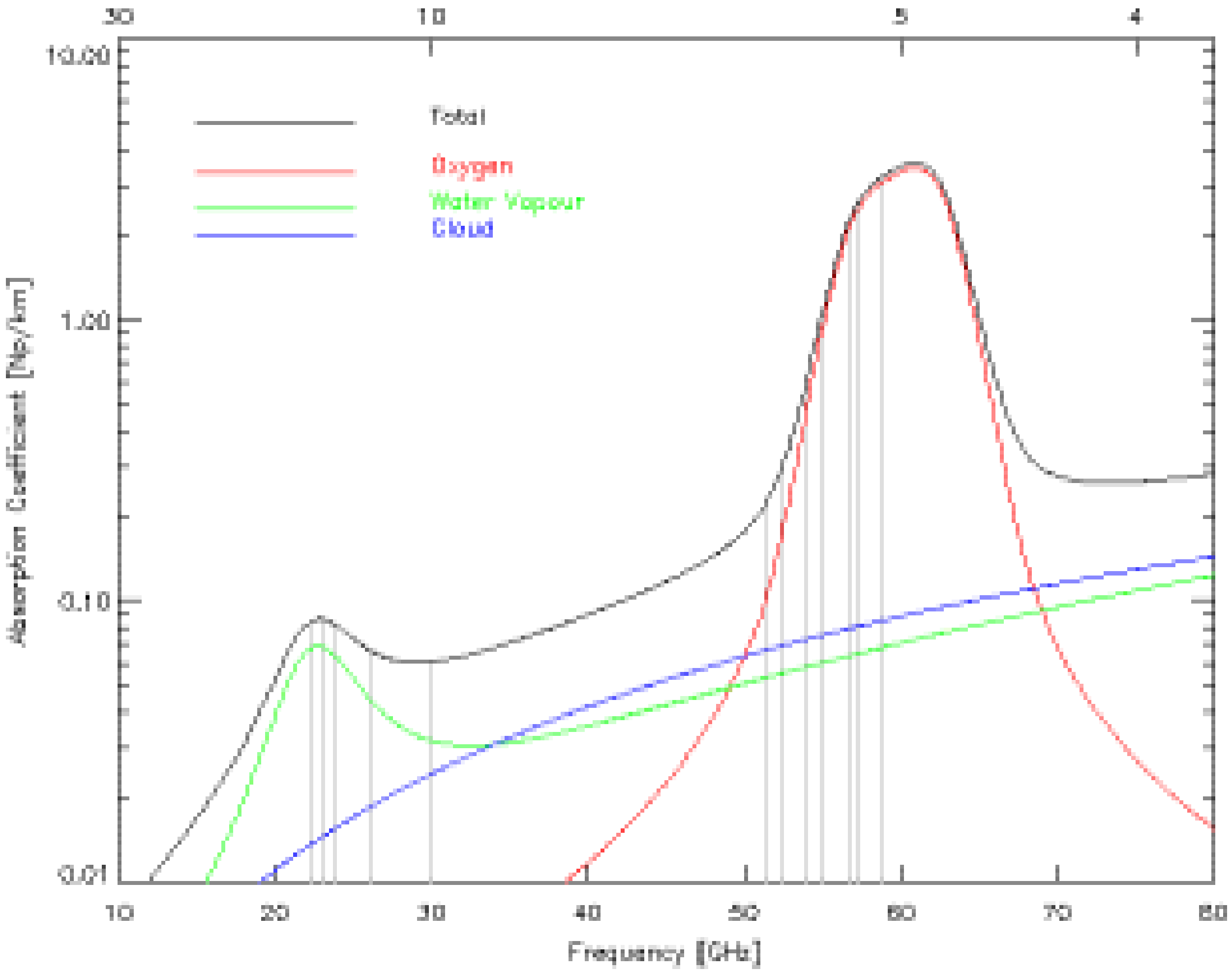
http://www.mike-willis.com/Tutorial/refraction.htm



http://dsp-book.narod.ru/RSAD/C1828_PDF_C08.pdf

Radar waves propagation

- **Atmosphere absorption**



Hewison T.J., Gaffard, C. (2006). 1D-VAR Retrieval of Temperature and Humidity Profiles from Ground-based Microwave Radiometers. *IEEE MicroRad, 2006*, 235–240, doi:10.1109/MICRAD.2006.1677095.

Radar cross-section

Radar cross-section

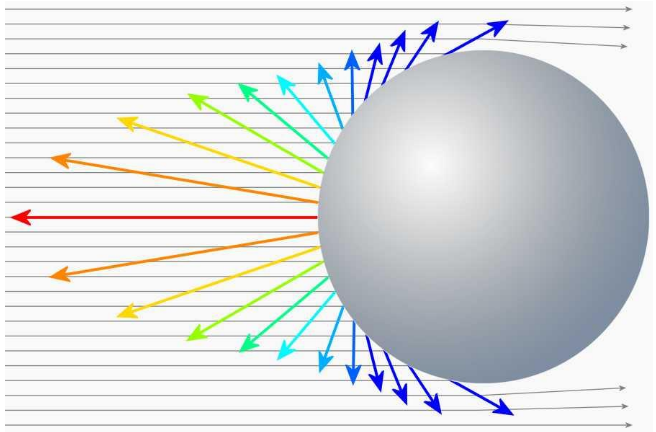
- **Radar cross-section (RCS), denoted σ, is a measure of theenergy that a radar target intercepts and scatters back toward the radar**.

σ = Projected surface x Reflectivity x Directivity
with Reflectivity : % of the transmitted power reflected by the target
Directivity: ratio between the power backscattered to the radar and the power backscattered by an isotropic source. The reference is a metallic sphere with a surface of 1 m^2

- An object reflects a limited amount of radar energy back to the source.

The RCS of a target depends on:

- the physical geometry and exterior features of the target,
- the direction of the illuminating radar,
- the radar transmitters frequency,
- the electrical properties of the target's surface.



https://www.radartutorial.eu/01.basics/Radar%20Cross%20Section.en.html

Radar cross-section

- When it can be computed, RCS [dBsm]:

  $\sigma S_t/4\pi = S_r \times r^2$

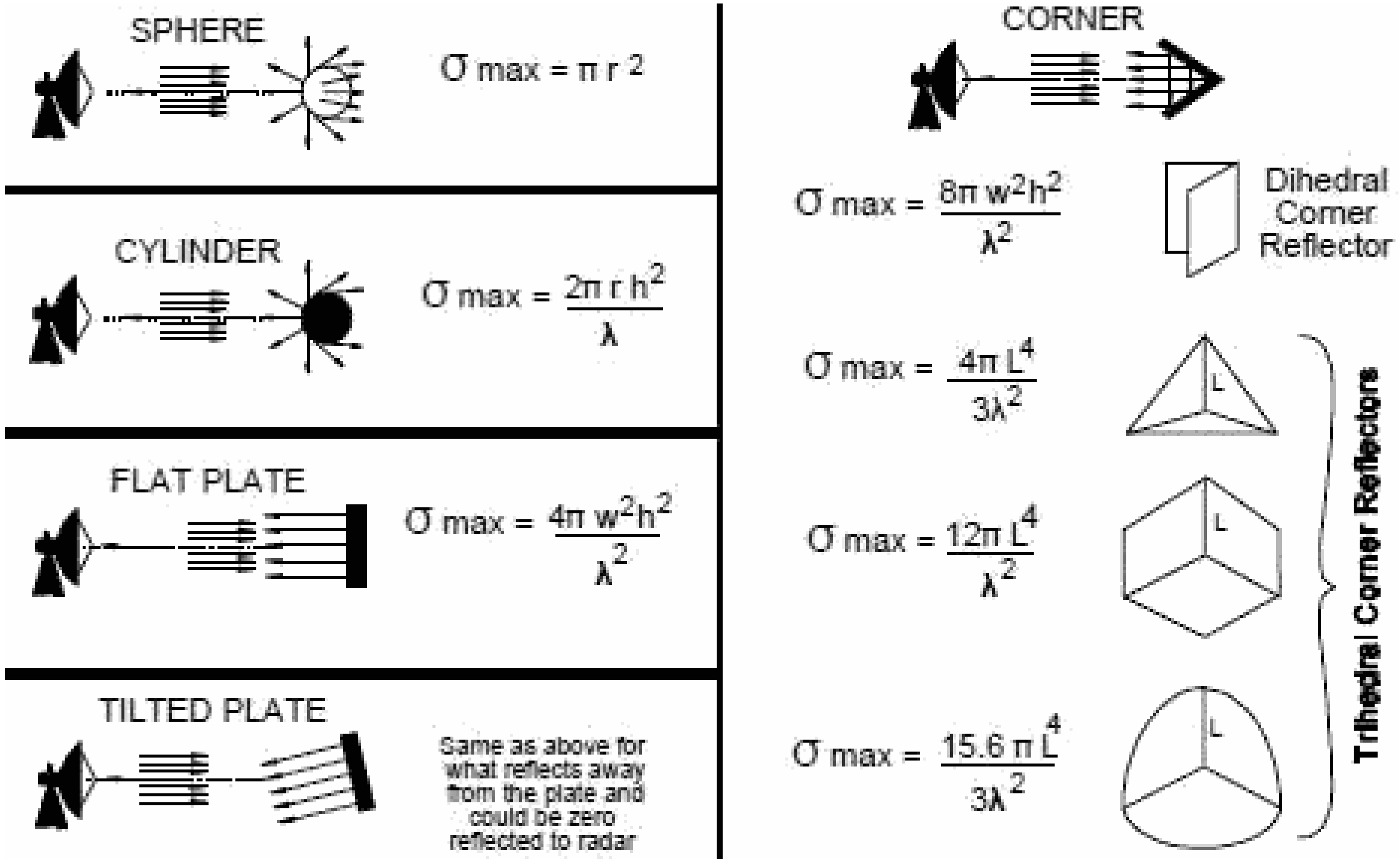
  with S_t : power density of the transmitter at the radar target in [W/m²]

  S_r : scattered power density at the receiving site in [W/m²]

  σS_t : power received and re-radiated by the radar target [W]

  $\sigma S_t/4\pi$: this power per solid angle, i.e. divided by 4π steradian [W/sr]

  r : radius of the sphere [m]



https://www.rfcafe.com/references/electrical/ew-radar-handbook/radar-cross-section.htm

Radar cross-section

Target Type	RCS, m²	RCS, dBsm
Insect or bird	10^{-5} to 10^{-2}	−50 to −20
Man	0.5 to 2	−3 to 3
Small aircraft	1 to 10	0 to 10
Large aircraft	10 to 100	10 to 20
Car or truck	100 to 300	20 to 25
Ship	200 to 1,000	23 to 30

http://it.leader-microwave.com/info/basic-knowledge-of-radar-scattering-cross-sect-39808128.html

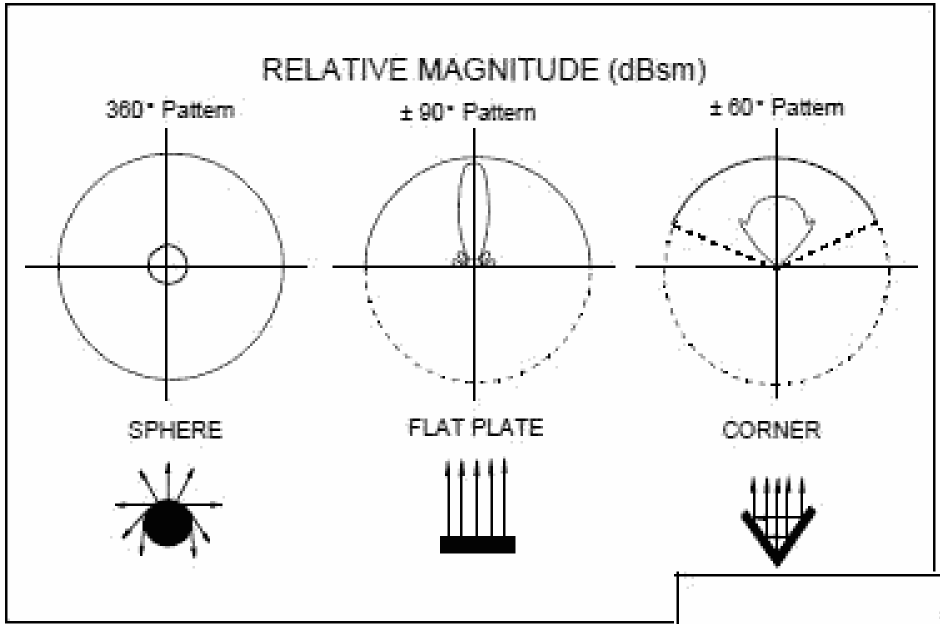


Figure 4. RCS Patterns

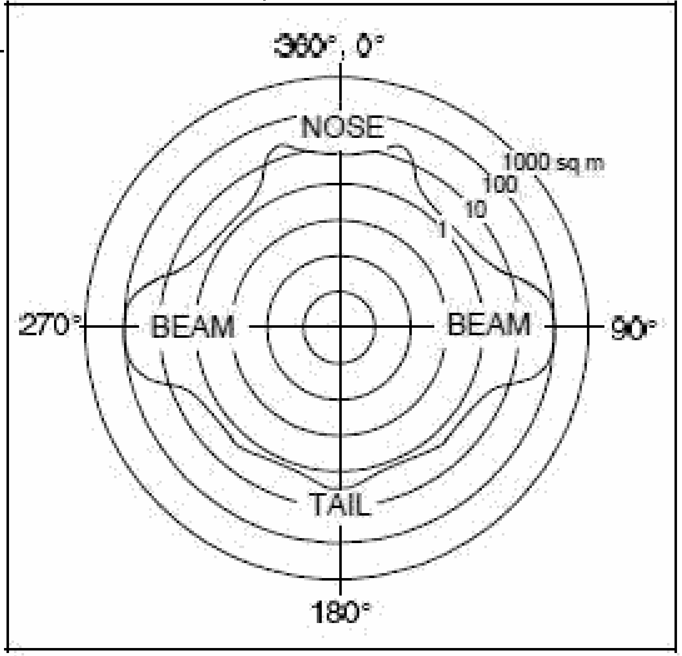


Figure 5. Typical Aircraft RCS

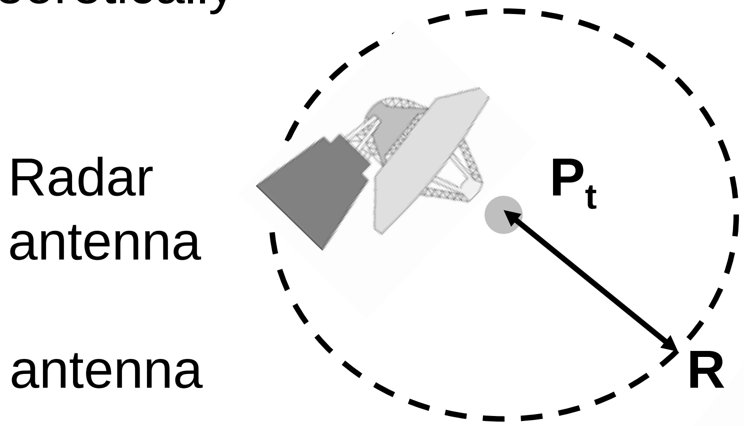
https://www.rfcafe.com/references/electrical/ew-radar-handbook/radar-cross-section.htm

Radar range equation

Radar range equation

❖ **The radar range equation represents the physical dependences of the transmit power, which is the wave propagation up to the receiving of the echo signals.**
It is useful to know the range of the target (R) theoretically

❖ Derivation of the radar range equation



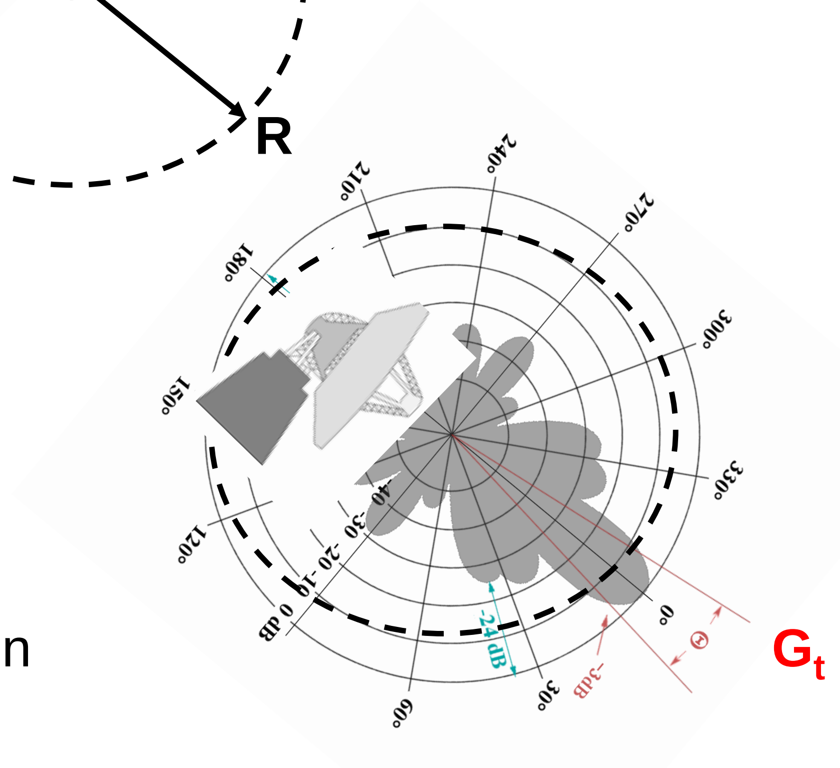
➢ Power density from uniformly radiating (istropic) antenna transmitting spherical wave: $\mathbf{P_t / (4\pi R^2)}$

with P_t : peak transmitter power

R : distance from radar

➢ Power density from directive antenna: $\mathbf{P_t G_t / (4\pi R^2)}$

with G_t : transmit gain



➢ The gain is the radiation intensity of the antenna in a given direction over that of an isotropic (uniformly radiating) source

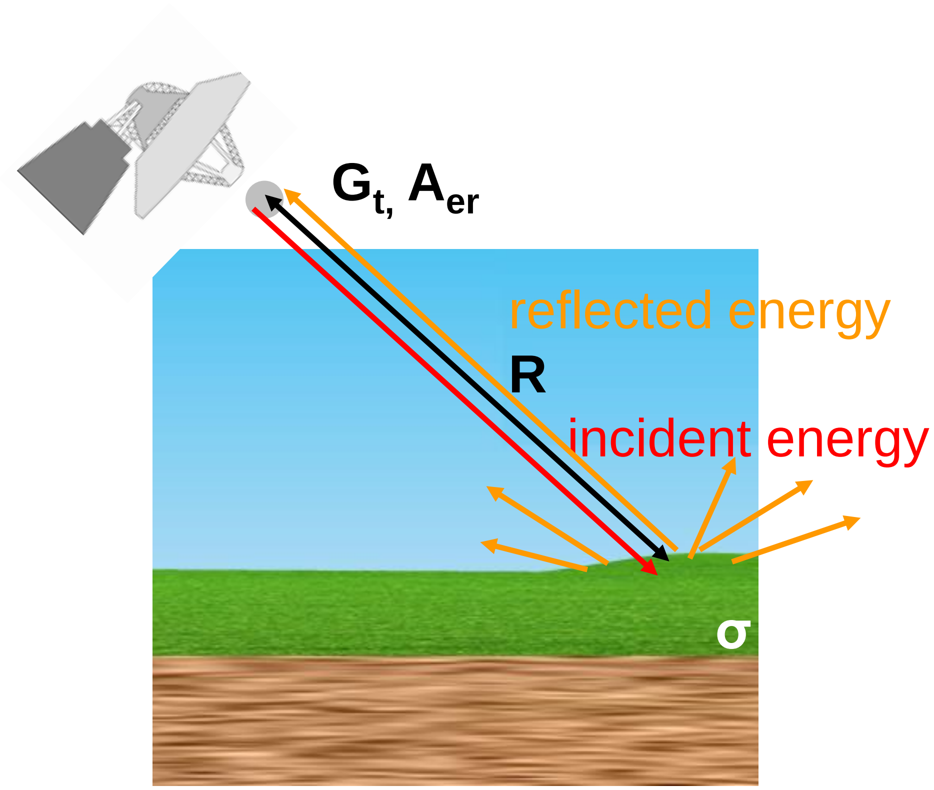
Radar range equation

- Gain: $\mathbf{G_t = 4 \pi A_{er} / \lambda^2}$
  with A_{er} : effective area of the radar antenna
  λ : wavelength

- Power of reflected signal at target:
  $\mathbf{P_t G_t / (4\pi R^2) \times \sigma}$
  with σ : radar cross-section (RCS)

- Power density of reflected signal at the radar:
  $\mathbf{P_t G_t / (4\pi R^2) \times \sigma / (4\pi R^2)}$

- Power of reflected signal from target and received by radar:
  $\mathbf{P_t G_t / (4\pi R^2) \times \sigma / (4\pi R^2)}$



Radar range equation

- Power of reflected signal from target and received by radar :

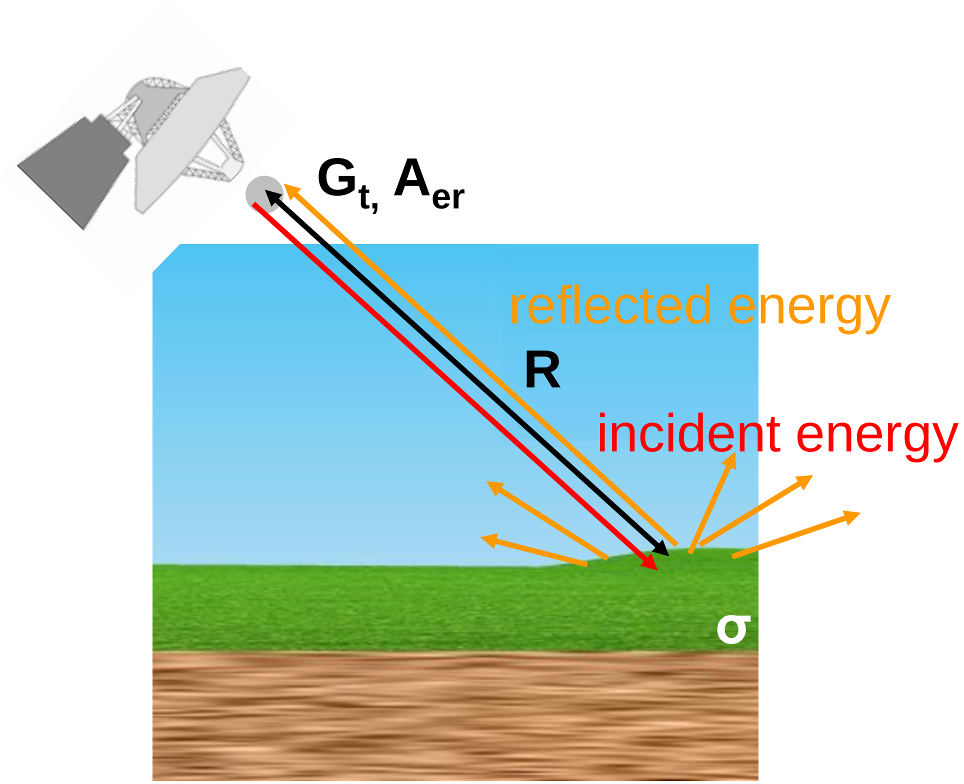
$$P_r = P_t G_t / (4\pi R^2) \times \sigma A_{er} / (4\pi R^2)$$

$$P_r = P_t G_t / (4\pi R^2) \times \sigma / (4\pi R^2) \times G_t \lambda^2 / 4\pi$$

- Maximum distance of detection:

$$R_{max} = [(P_t G_t^{2} \sigma \lambda^2) / ((4\pi)^3 P_{min})]^{1/4}$$

with P_{min} : minimum power that can be detected



Sources of noise received by radars

- The total effect of the noise sources is represented by a single noise source at the antenna output terminal:

$$P_r = P_t\, G_t / (4\pi R^2) \times \sigma\, A_{er} / (4\pi R^2)$$

$$P_r = P_t\, G_t / (4\pi R^2) \times \sigma / (4\pi R^2) \times G_t\, \lambda^2 / 4\pi$$

- The noise power (N) at the receiver is given by: :

$$N = k_B\, B_n\, T_s$$

with $k_B = 1.38 \times 10^{-23}$ J/K
Boltzman's constant
B_n : noise bandwidth of receiver
T_s : system noise temperature

- **Signal to Noise Ratio: S / N = Pr / N**

$$S / N = (P_t\, G_t^{\,2}\, \sigma\, \lambda^2) / ((4\pi)^3 R^4\, k_B\, B_n\, T_s\, L)$$

with L: total system losses