Radar Physics

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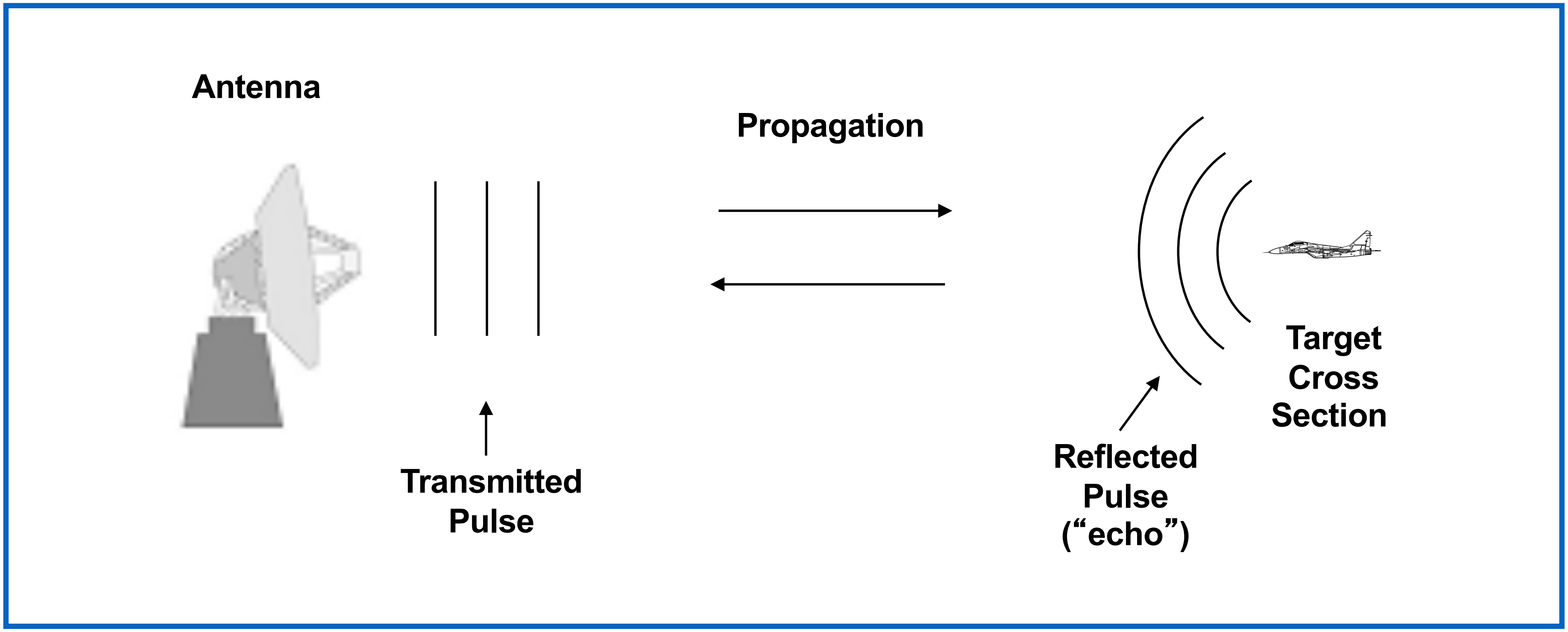
Outline

Radar fundamentals

Radar equation

RADAR

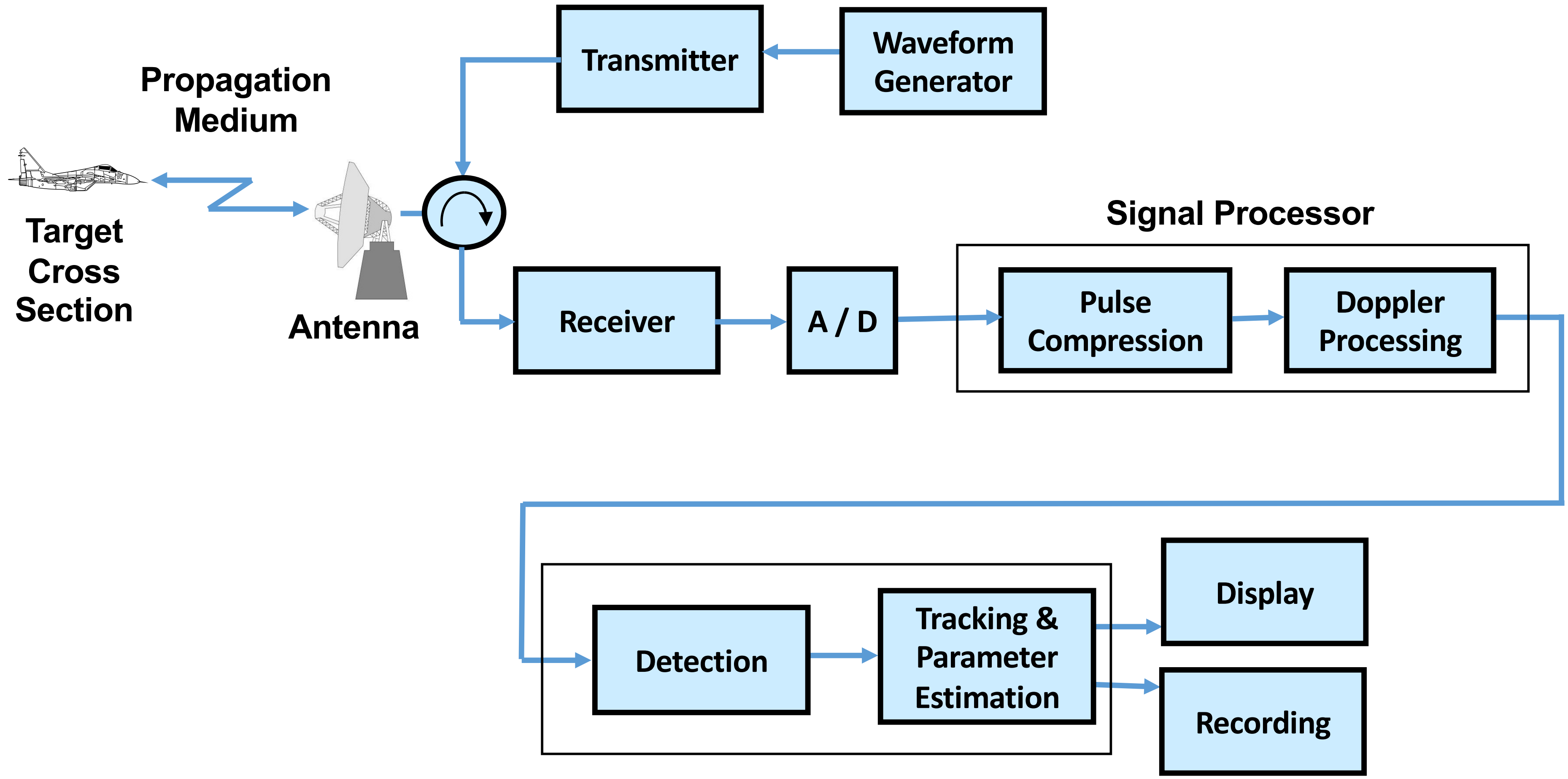
RAdio Detection And Ranging



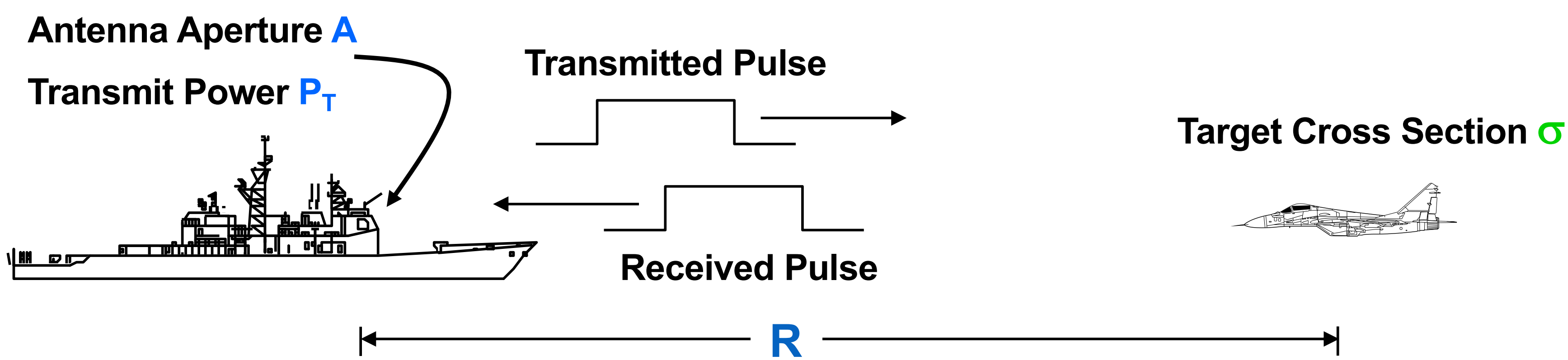
Radar observables:

- Target range
- Target angles (azimuth & elevation)
- Target size (radar cross section)
- Target speed (Doppler)
- Target features (imaging)

Radar Block Diagram



Radar Range Equation

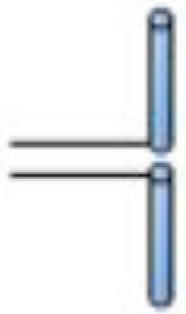


Transmit Power	Transmit Gain	Spread Factor	Losses	Target RCS	Spread Factor	Receive Aperture	Dwell Time
$[P_T]$	$\left[\frac{4\pi A}{\lambda^2}\right]$	$\left[\frac{1}{4\pi R^2}\right]$	$\left[\frac{1}{L}\right]$	$[\sigma]$	$\left[\frac{1}{4\pi R^2}\right]$	$[A]$	$[\tau]$

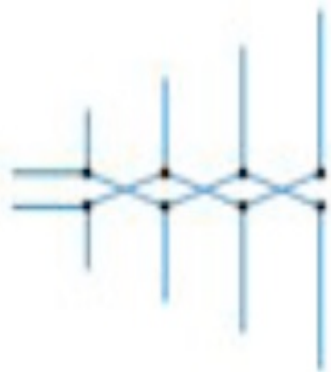
$$\text{Received Signal Energy} = [P_T]\left[\frac{4\pi A}{\lambda^2}\right]\left[\frac{1}{4\pi R^2}\right]\left[\frac{1}{L}\right][\sigma]\left[\frac{1}{4\pi R^2}\right][A][\tau]$$

Antennas

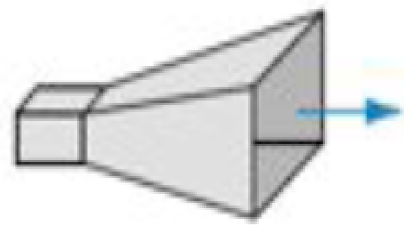
Most basic form of antennas – a wire element with a time varying current flowing in it



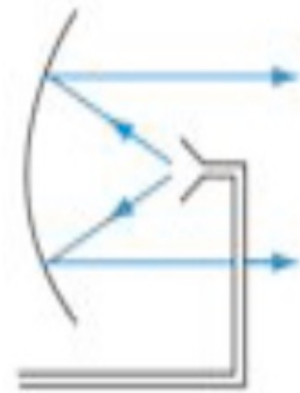
Dipole antenna



Log periodic

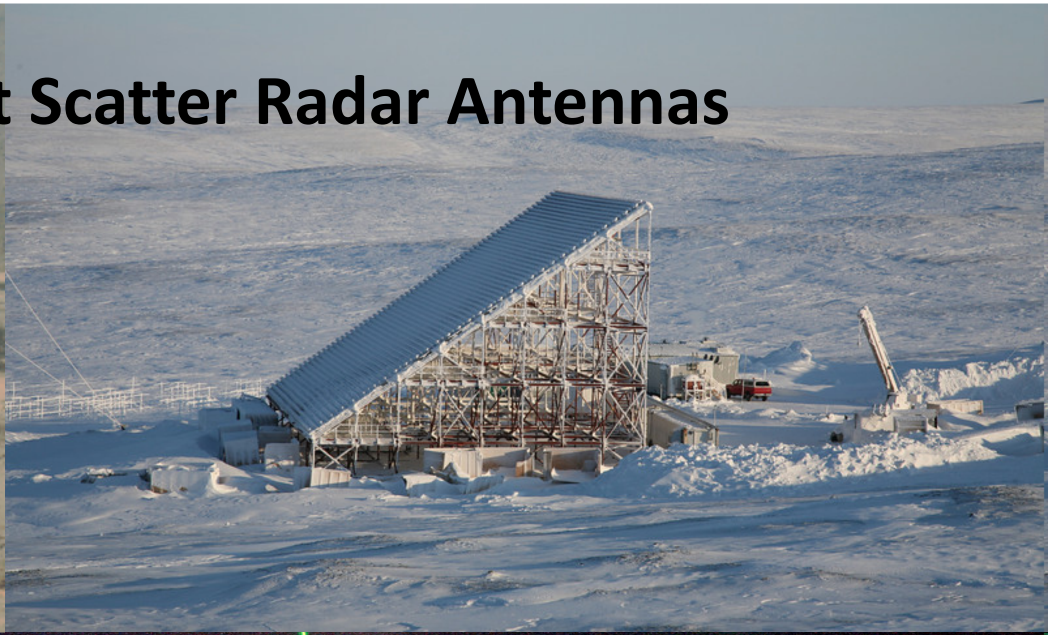


Horn antenna



Parabolic dish
Reflector antenna

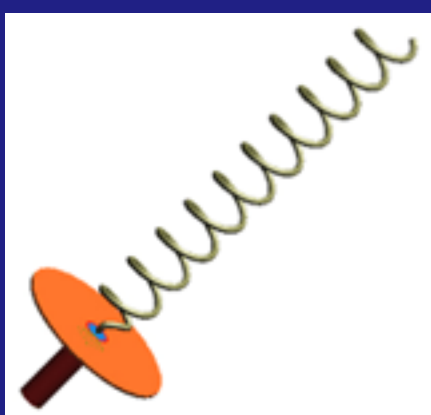
Examples of Incoherent Scatter Radar Antennas



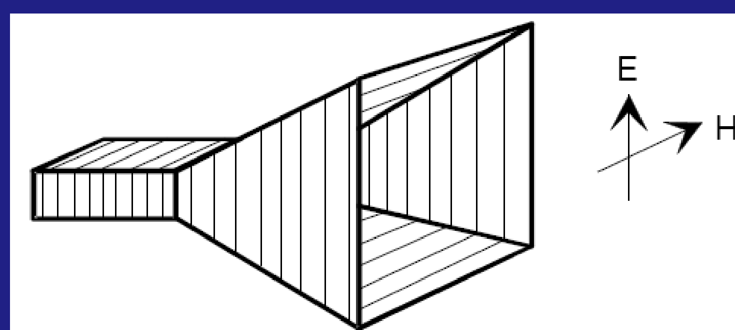
Antennas

Four primary functions of an antenna for radar applications:

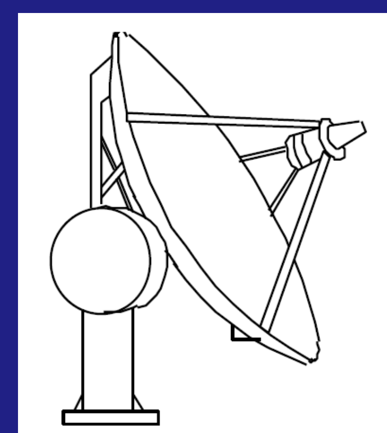
- Impedance transformation (free-space intrinsic impedance to transmission-line characteristic impedance)
- Propagation-mode adapter (free-space fields to guided waves)
- Spatial filter (radiation pattern – direction-dependent sensitivity)
- Polarization filter (polarization-dependent sensitivity)



Helical antenna



Horn antenna



Parabolic reflector antenna

Impedance transformer

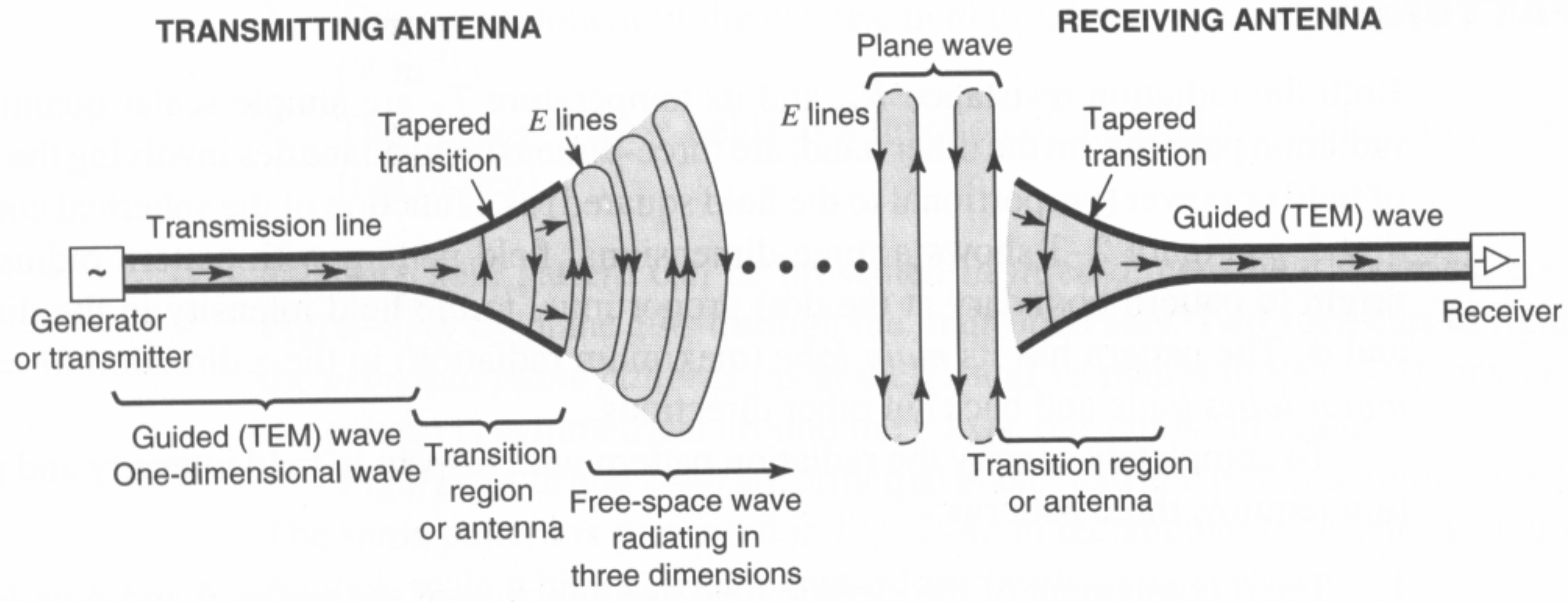
- Intrinsic impedance of free-space, $\eta_o \equiv E/H$ is

$$\eta_0 = \sqrt{\mu_0/\varepsilon_0} = 120\,\pi \cong 376.7\,\Omega$$

- Characteristic impedance of transmission line, $Z_o = V/I$
- A typical value for Z_o is 50 Ω.
- Clearly there is an impedance mismatch that must be addressed by the antenna.

Propagation-mode adapter

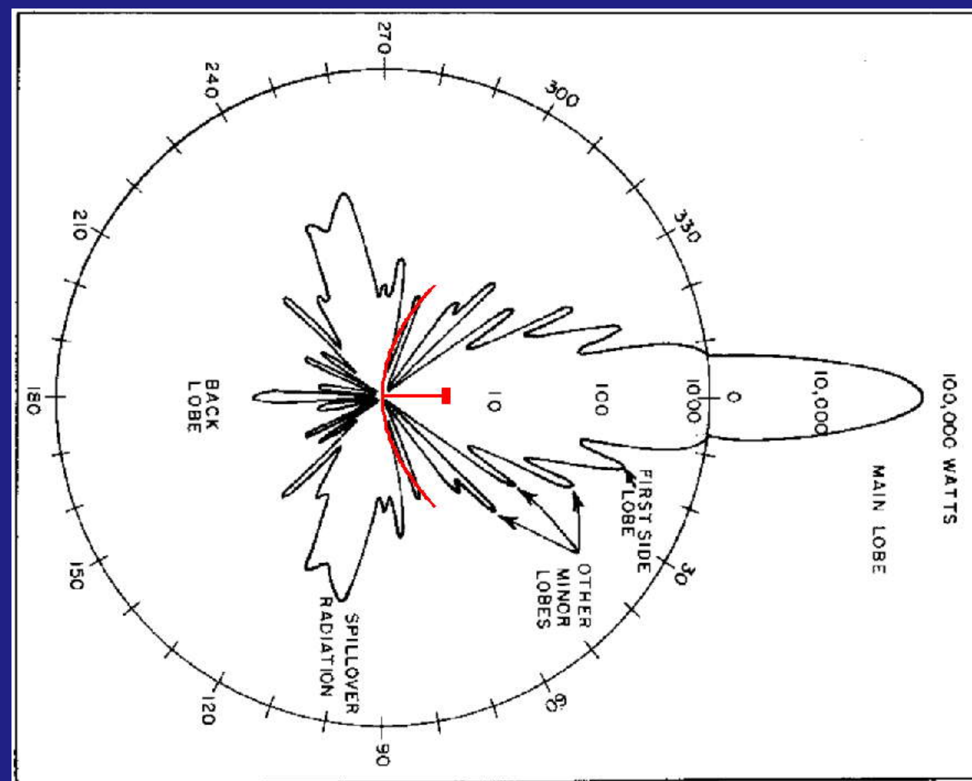
During both transmission and receive operations, the antenna must provide the transition between these two propagation modes.



Spatial filter

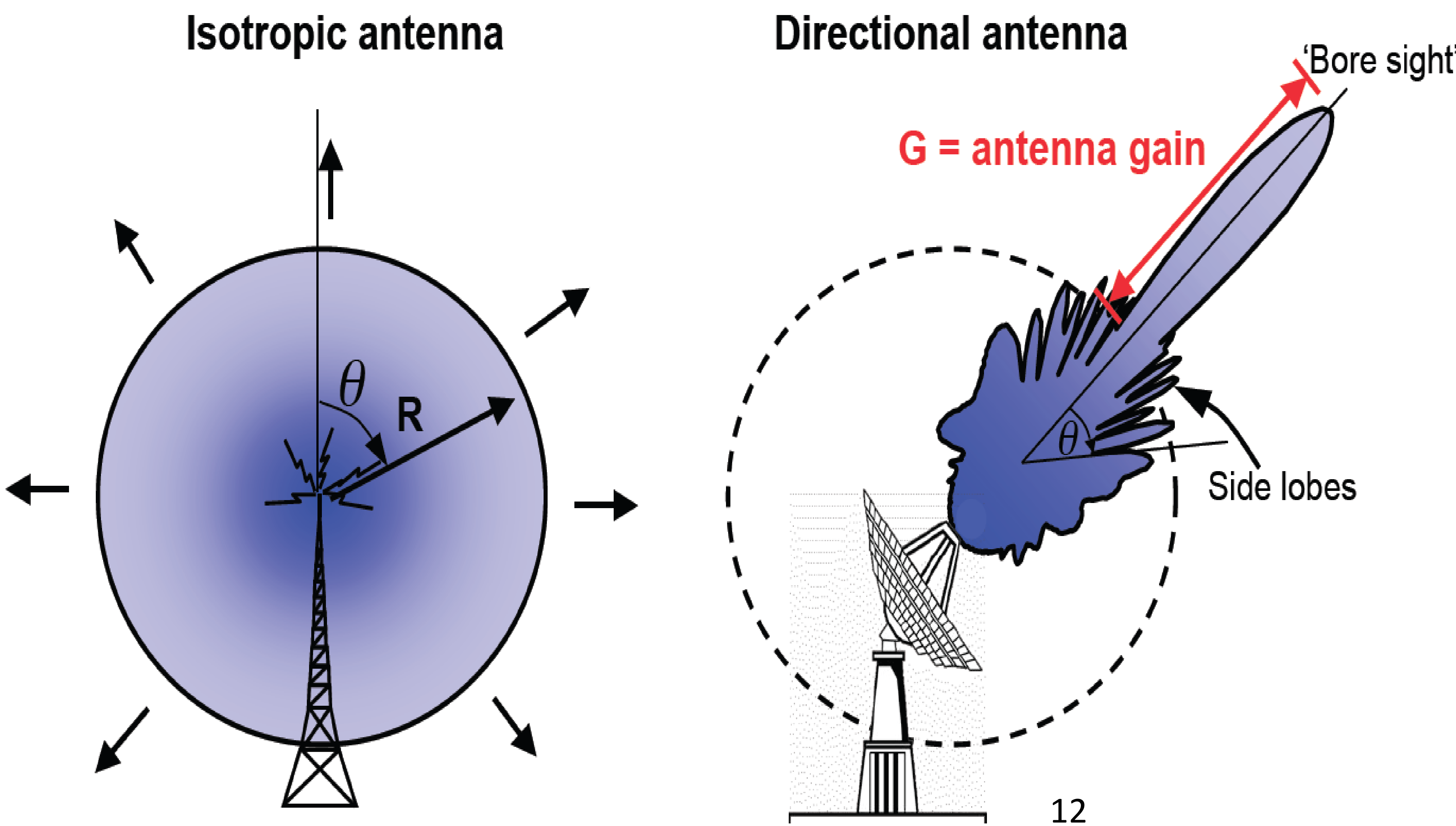
Antennas have the property of being more sensitive in one direction than in another, which provides the ability to spatially filter signals from its environment.

Directive antenna.



Radiation pattern of directive antenna.

Radiation pattern – antenna gain



Polarization filter

Antennas have the property of being more sensitive to one polarization than another. This provides the ability to filter signals based on its polarization.

Example: Satellite tracking receive on both right-circular and left-circular

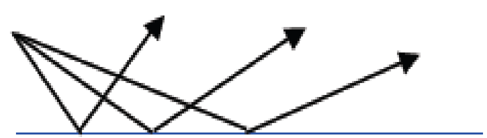
Propagation medium – Losses

Radio waves are affected by the medium they propagate in. Effects dependent on the refractive index of the medium and wave frequency

Radio waves are also reflected off of the surface

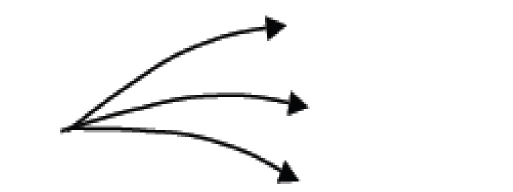
- **Atmospheric attenuation**

- **Reflection off of earth's surface**



- **Over-the-horizon diffraction**

- **Atmospheric refraction**



Attenuation usually measured in dB

$$\text{SNR dB} = 10\log_{10}\frac{\text{signal power}}{\text{noise power}}$$

dB value	times by
+30 dB	1000
+20 dB	100
+3 dB	2
-10 dB	0.1
-20 dB	0.01

Radar equation

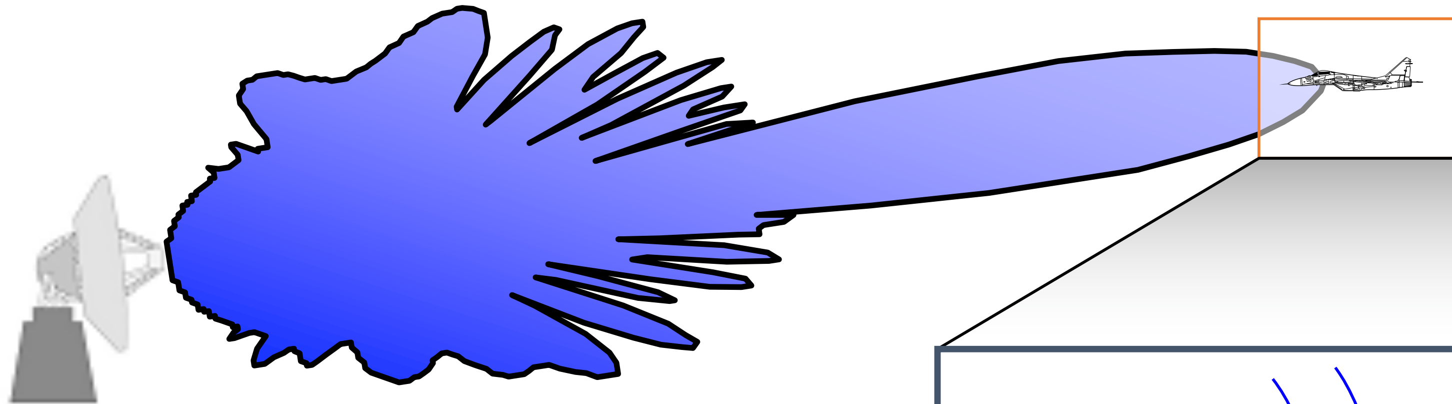
Received Signal Energy	=	Transmit Power	Transmit Gain	Spread Factor	Losses	Target RCS	Spread Factor	Receive Aperture	Dwell Time

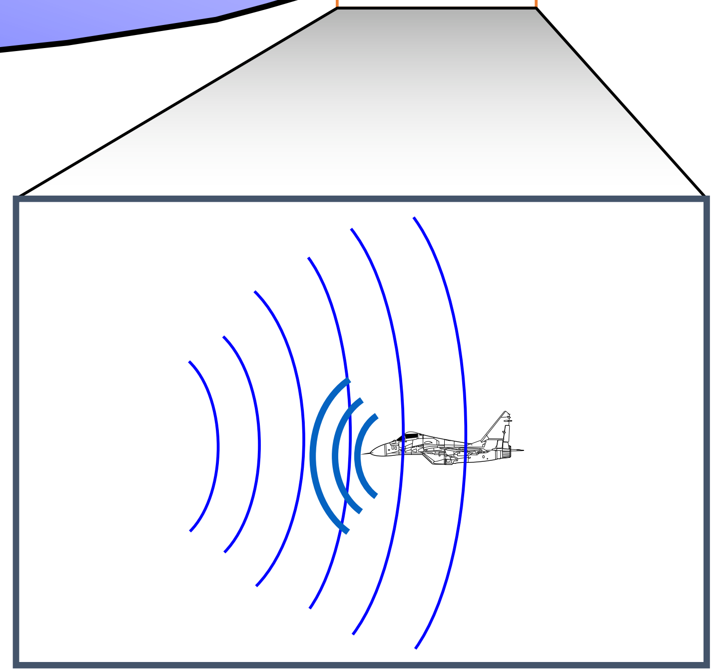
$$\text{Received Signal Energy} = [P_T]\left[\frac{4\pi A}{\lambda^2}\right]\left[\frac{1}{4\pi R^2}\right]\left[\frac{1}{L}\right][\sigma]\left[\frac{1}{4\pi R^2}\right][A][\tau]$$

Radar cross section tells us about the target properties

It is the effective target cross section as seen by the radar

Radar Cross Section (RCS)





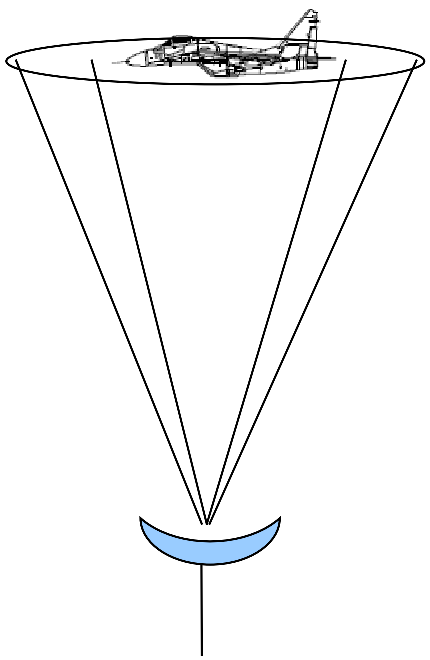
RCS

Incident Power Density (Watts/m^2) x σ (m^2) = Reflected Power (Watts)

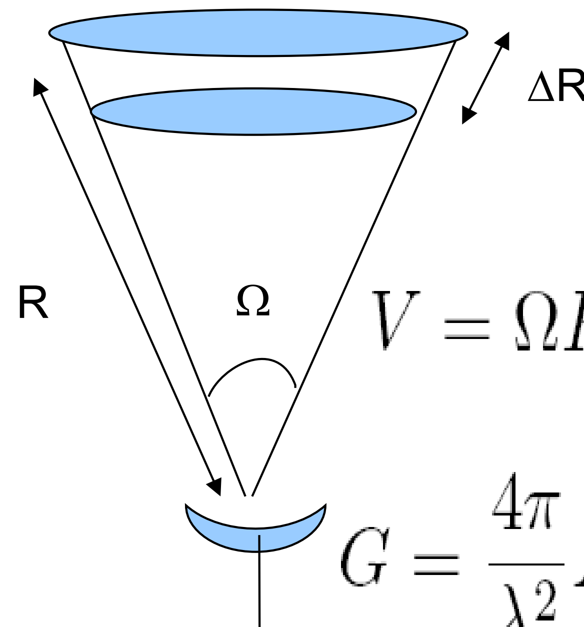
Radar Cross Section (RCS, or s) is the *effective* cross-sectional area of the target as seen by the radar

measured in m^2, or dBm^2

Hard targets vs. Soft targets



vs.



$$V = \Omega R^2 \, \Delta R$$

$$G = \frac{4\pi}{\lambda^2} A = \frac{4\pi}{\Omega}$$

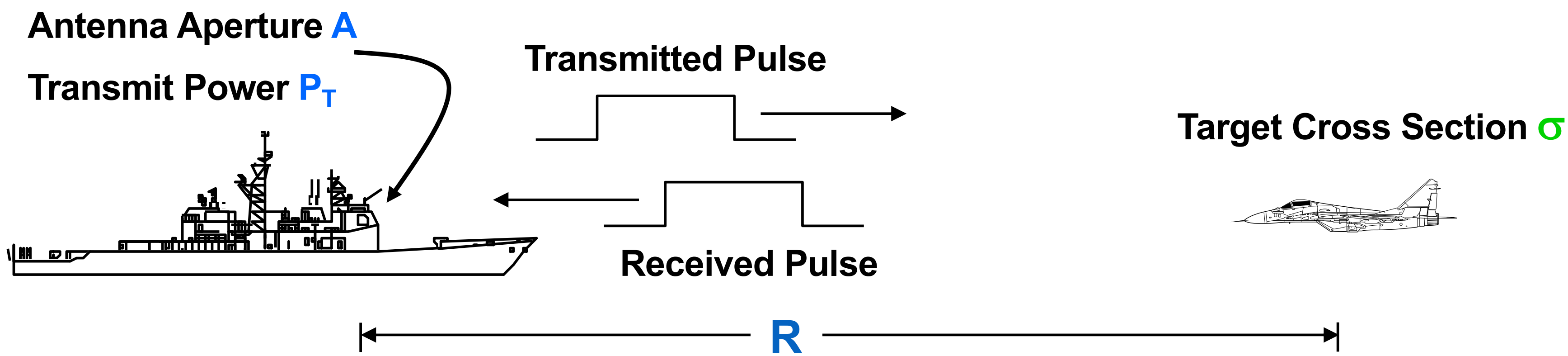
$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

$$P_r = \frac{P_t A \sigma_v \Delta R}{4\pi R^2}$$

Volume scattering - Ionosphere

- Volume scattering cross section σ_v has area/volume units
- Signal is proportional to range resolution
- What about the ionosphere ?
  - Cross section of a single electron = 10^{-28} m^2
  - Cross section of a bunch of electrons in a 10 km^3 volume in the ionosphere assuming electron density = 10^{12} /m^3, is 10^{10} x 10^{12} x 10^{-28} = 10^{-6} m^2 !!)
  - **CAN be measured by an incoherent scatter radar.**

Radar Range Equation



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