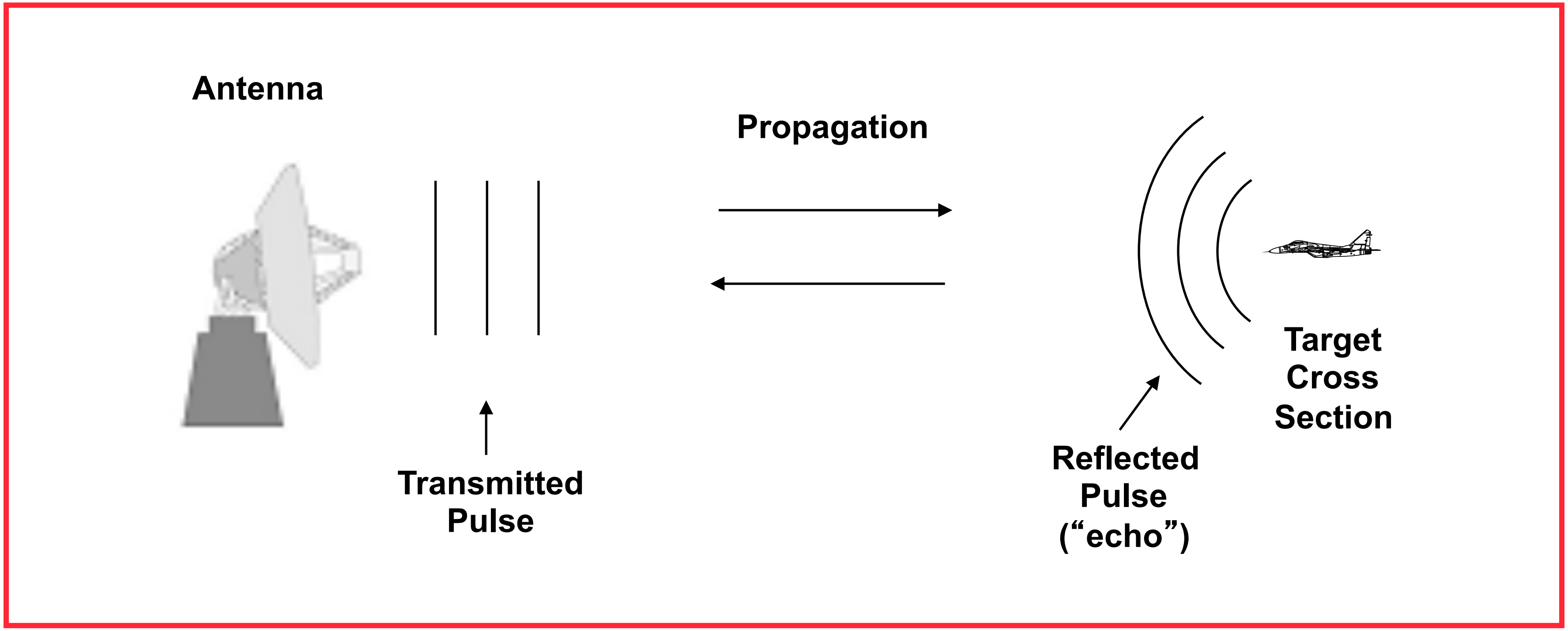
RADAR

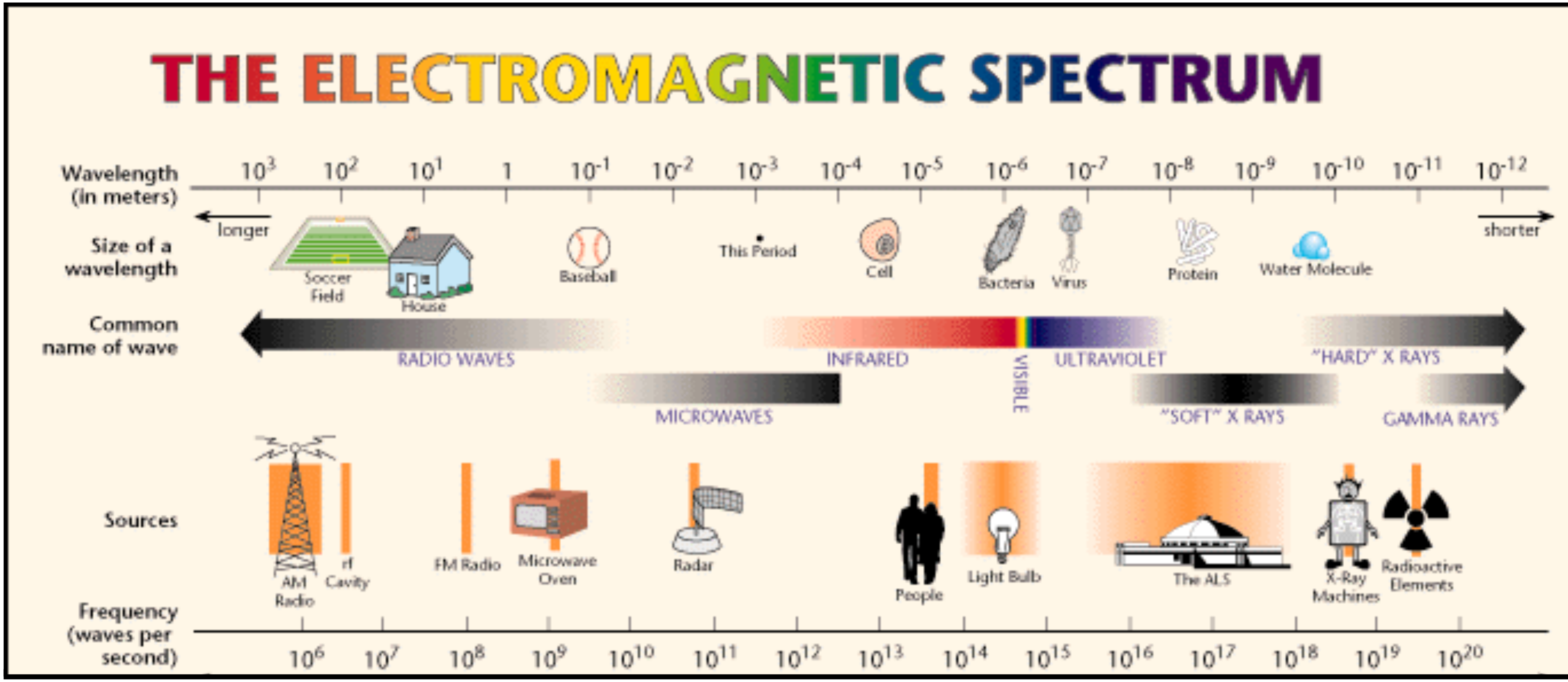
RAdio Detection And Ranging



Radar observables:

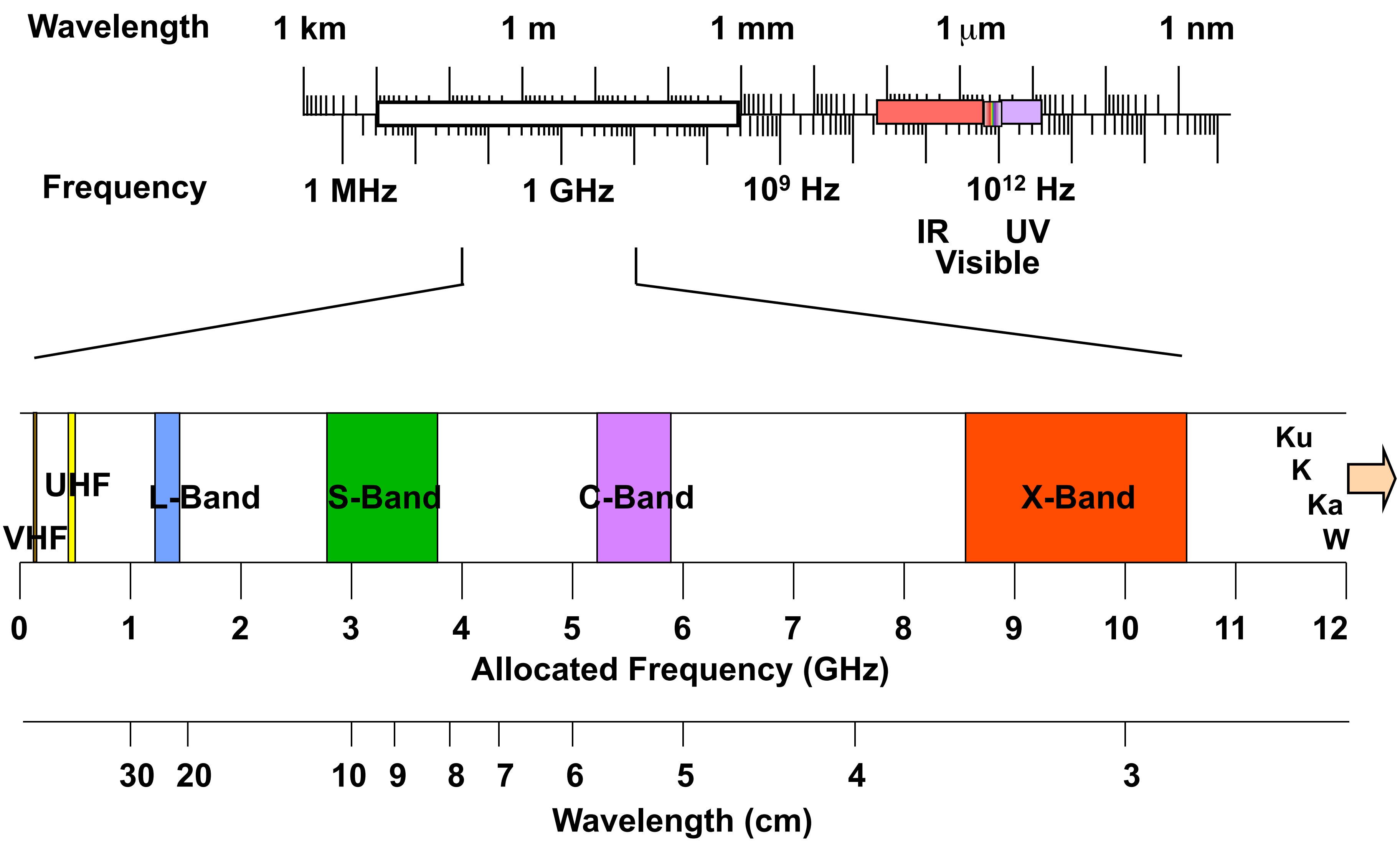
- Target range
- Target angles (azimuth & elevation)
- Target size (radar cross section)
- Target speed (Doppler)
- Target features (imaging)

Electromagnetic Waves



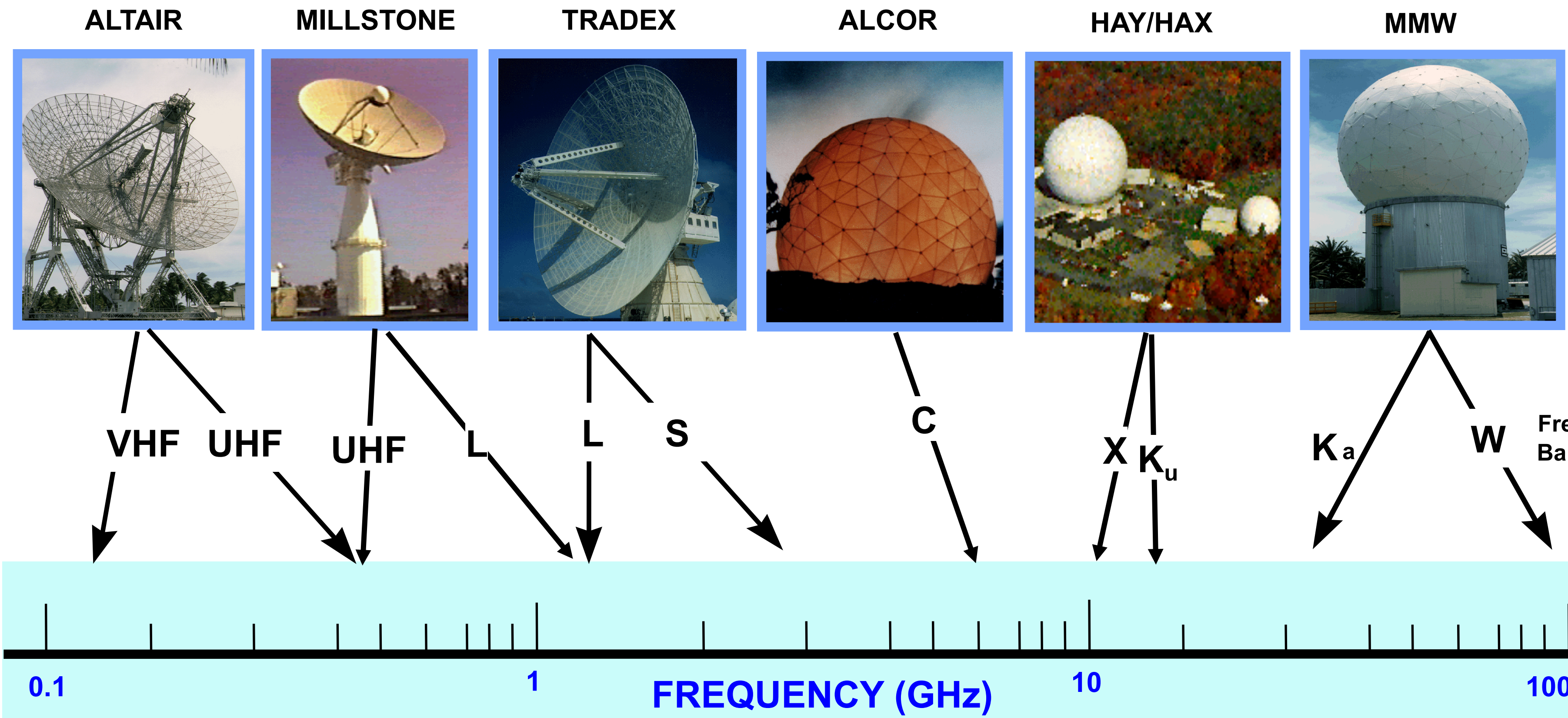
Radar Frequencies

Radar Frequency Bands



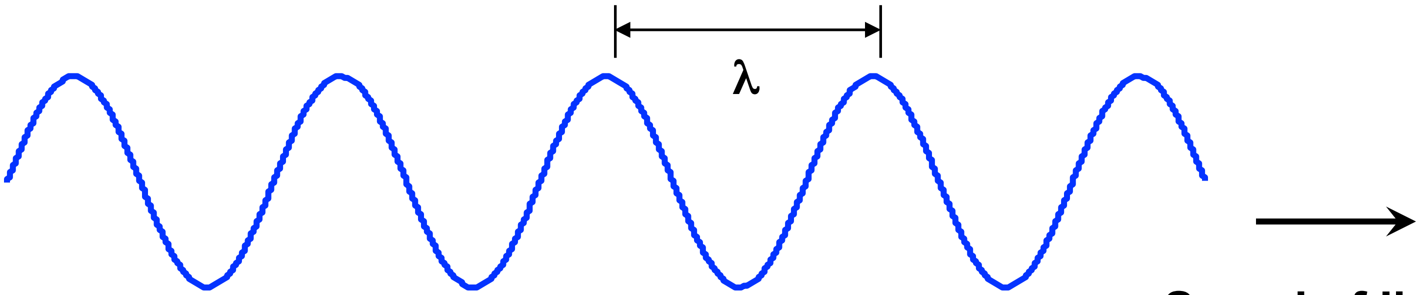
Lincoln Laboratory Satellite Tracking Radars

Frequency Bands



Properties of Waves

Relationship Between Frequency and Wavelength



Speed of light, c

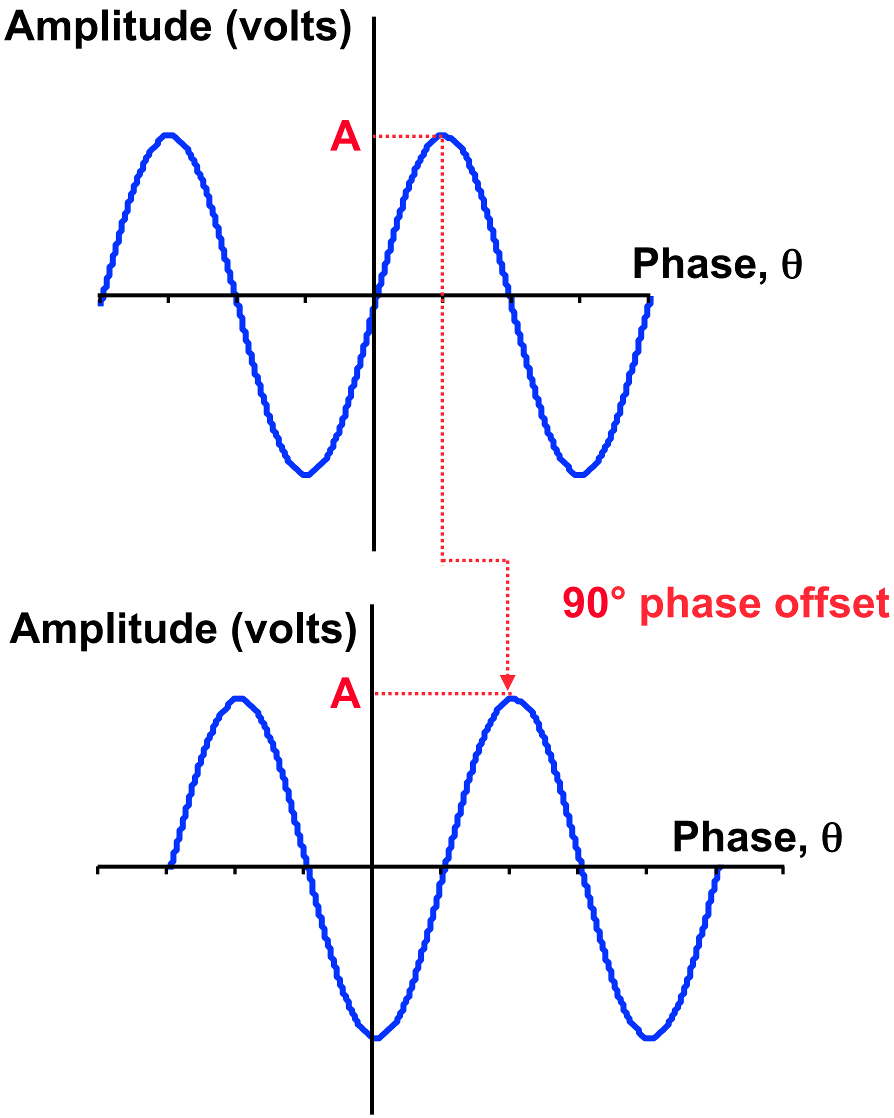
$c = 3\text{x}10^8$ m/sec
$= 300{,}000{,}000$ m/sec

$$\text{Frequency (1/s)} = \frac{\text{Speed of light (m/s)}}{\text{Wavelength } \lambda \text{ (m)}}$$

Examples:

Frequency	Wavelength
100 MHz	3 m
1 GHz	30 cm
3 GHz	10 cm
10 GHz	3 cm

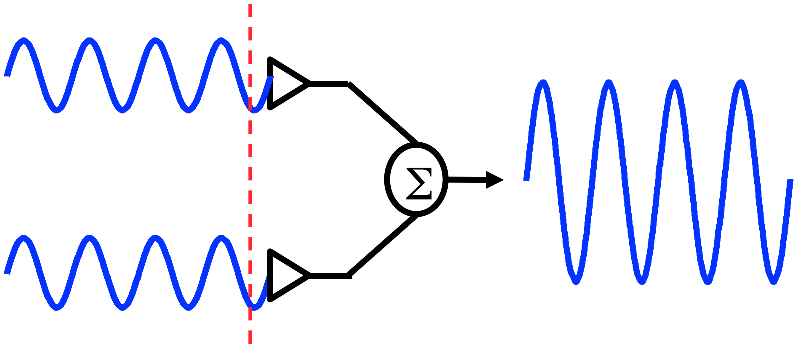
Properties of Waves
Phase and Amplitude



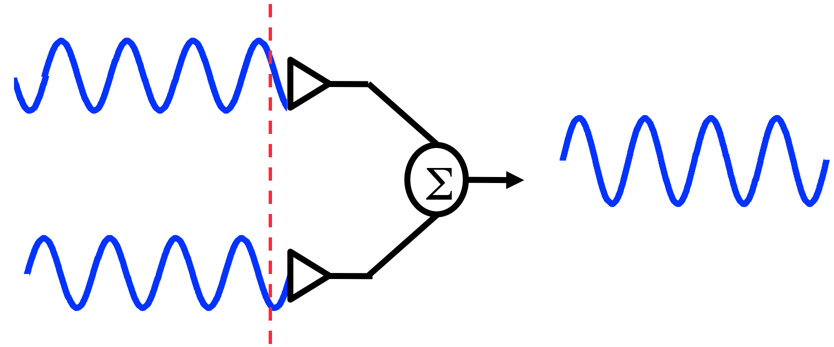
$$A \sin(\theta)$$

$$A \sin(\theta - 90^{o})$$

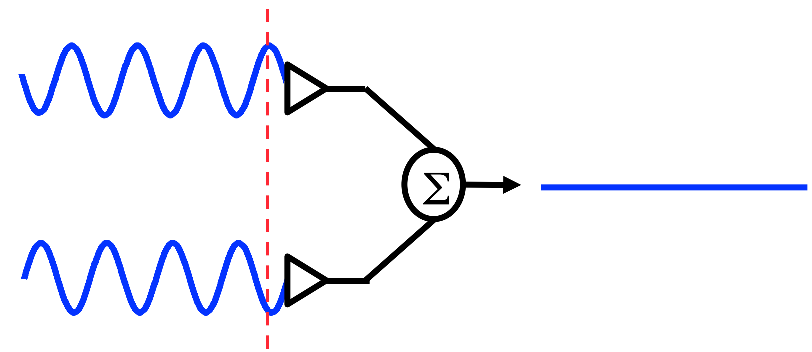
Properties of Waves
Constructive vs. Destructive Addition



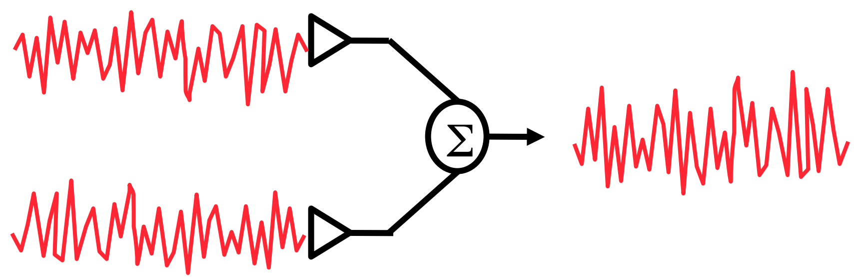
Constructive
(in phase)



Partially Constructive
(somewhat out of phase)



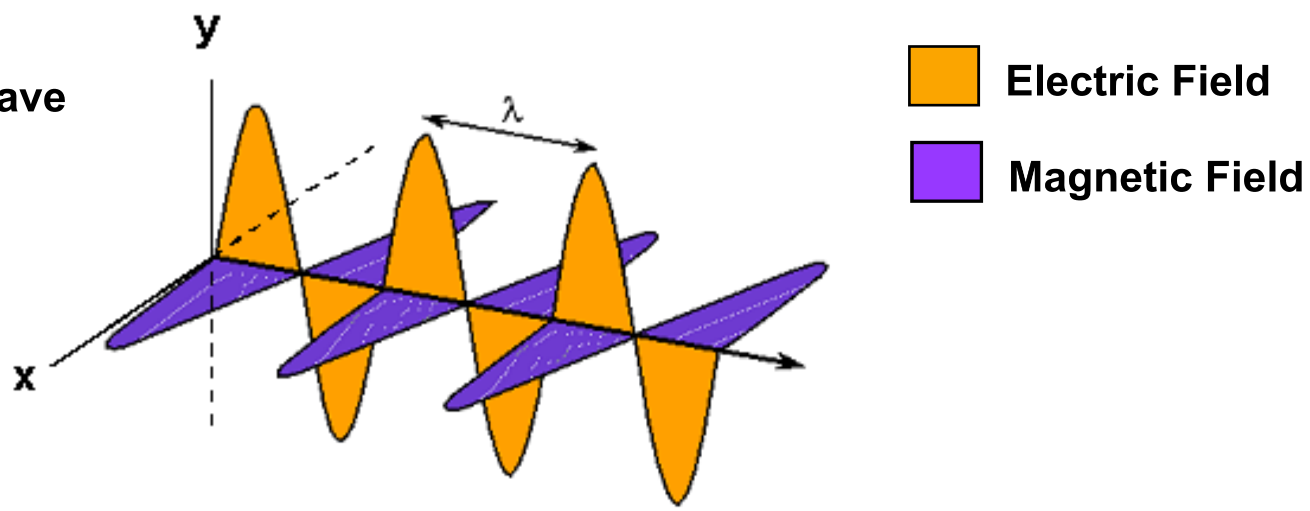
Destructive
(180° out of phase)



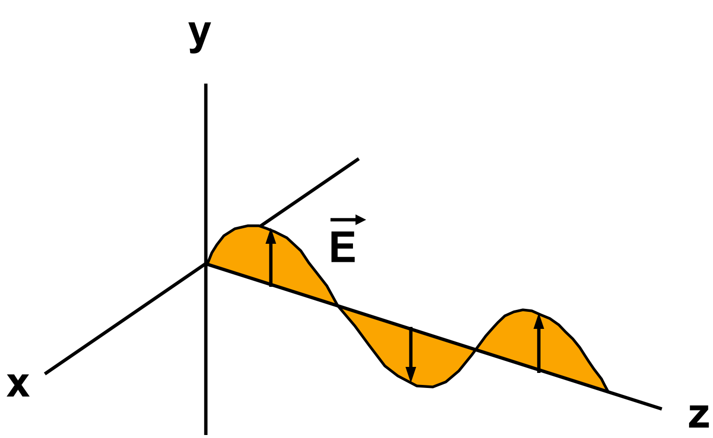
Non-coherent signals
(noise)

Polarization

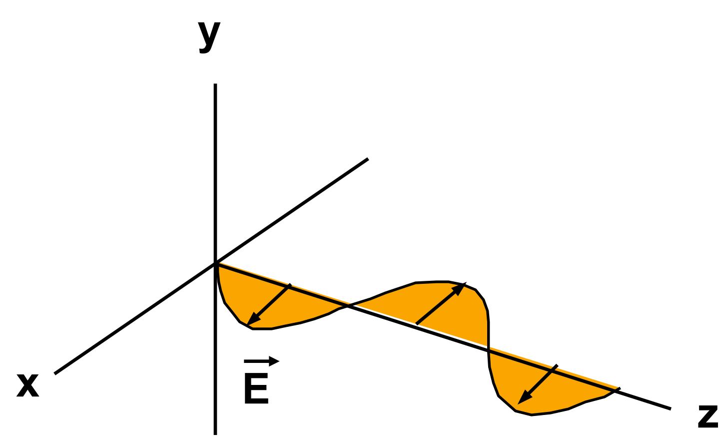
Electromagnetic Wave



Vertical Polarization



Horizontal Polarization



RADAR

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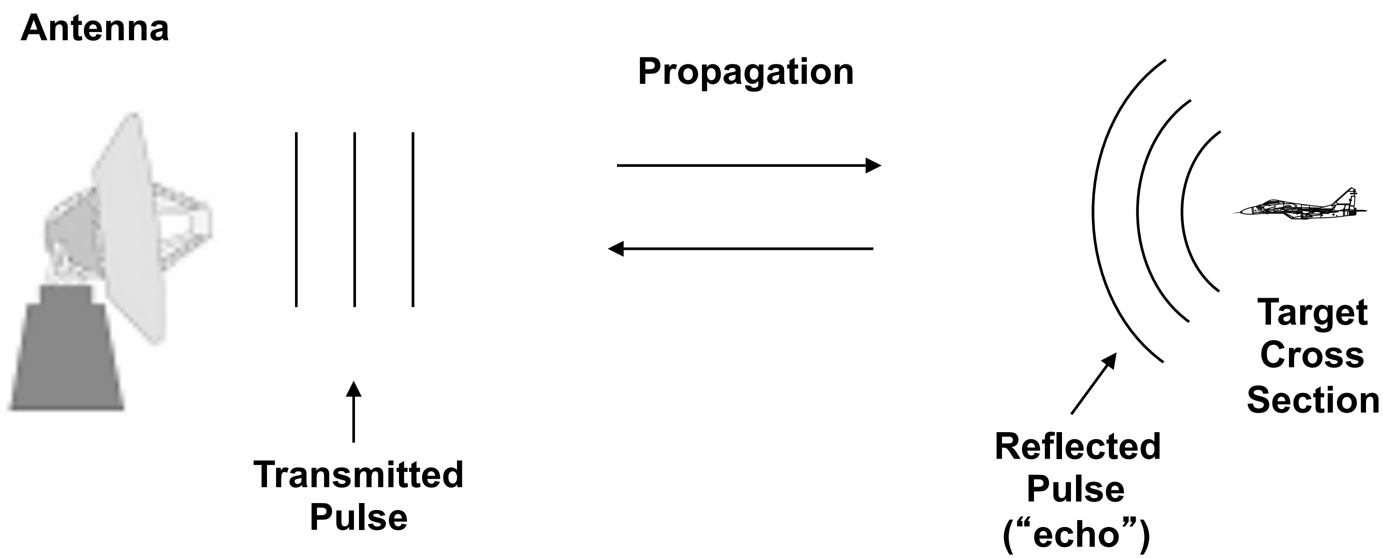
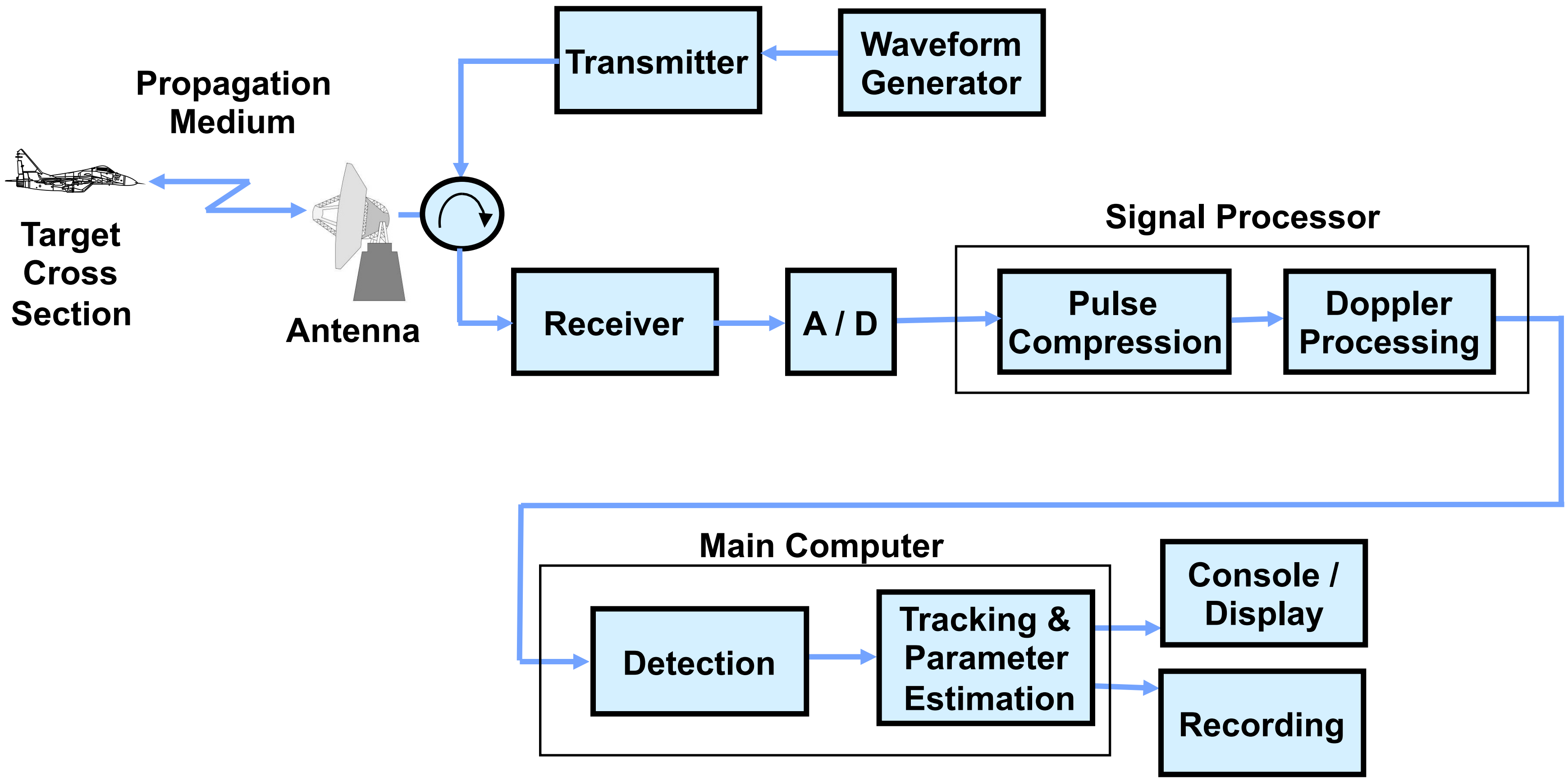


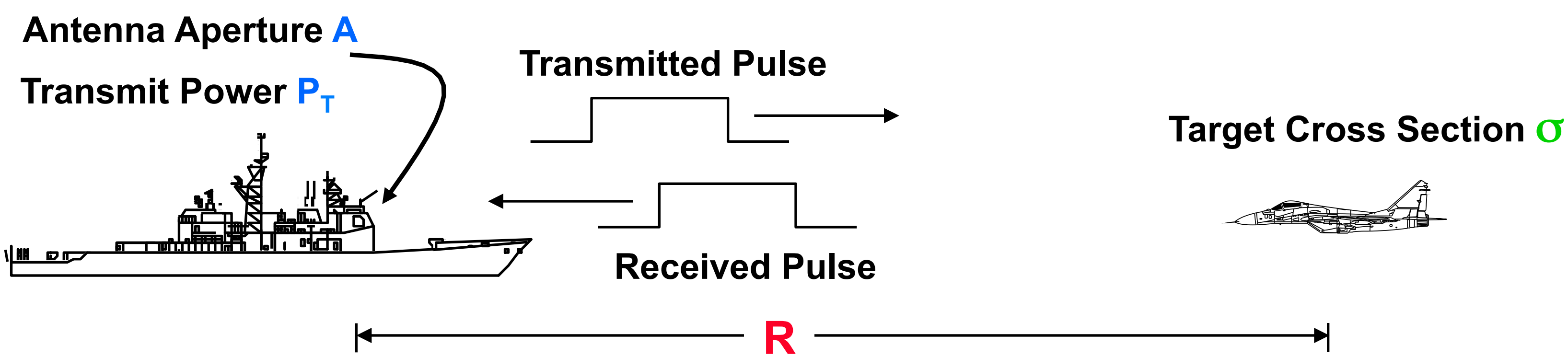
Radar observables:

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

Radar Block Diagram



Radar Range Equation



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

Definition of a dB

The relative value of two things, measured on a logarithmic scale, is often expressed in deciBell's (dB)

Example:

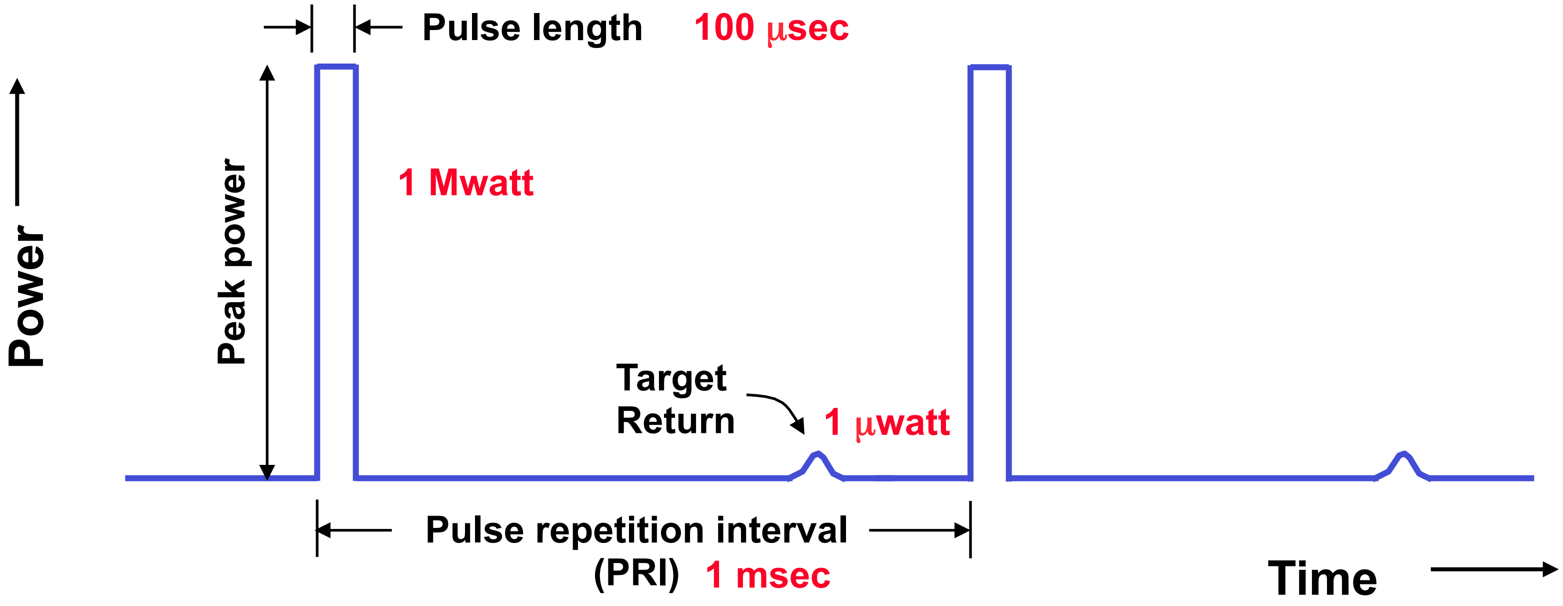
$$\text{Signal-to-noise ratio (dB)} = 10 \log_{10} \left[\frac{\text{Signal Power}}{\text{Noise Power}} \right]$$

Factor of:	Scientific Notation	dB
10	10^1	10
100	10^2	20
1000	10^3	30
.		
.		
.		
1,000,000	10^6	60

0 dB = factor of 1
-10 dB = factor of 1/10
-20 dB = factor of 1/100

3 dB = factor of 2
-3 dB = factor of 1/2

Pulsed Radar
Terminology and Concepts

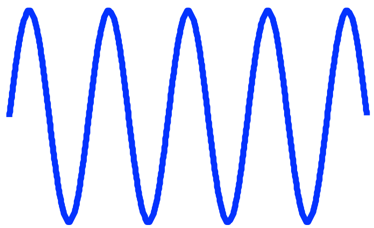


Duty cycle =	$\frac{\text{Pulse length}}{\text{Pulse repetition interval}}$	10%
Average power = Peak power * Duty cycle		100 kWatt
Pulse repetition frequency (PRF) = 1/(PRI)		1 kHz

Continuous wave (CW) radar: Duty cycle = 100% (always on)

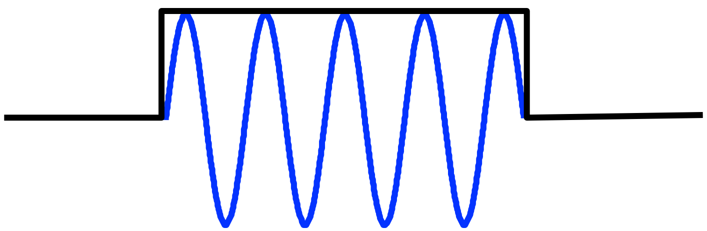
Radar Waveforms

What do radars transmit?



Waves?

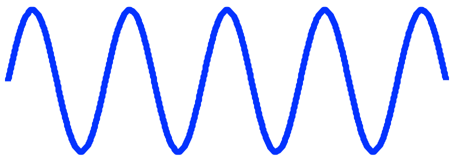
or Pulses?

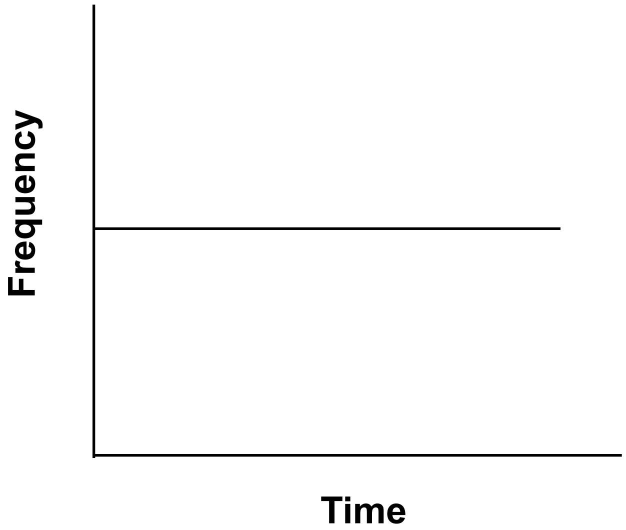


Waves, modulated by "on-off" action of pulse envelope

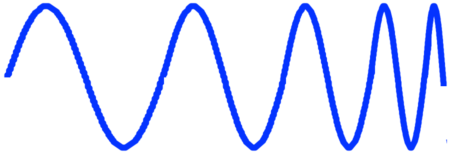
Radar Waveforms (cont'd.)

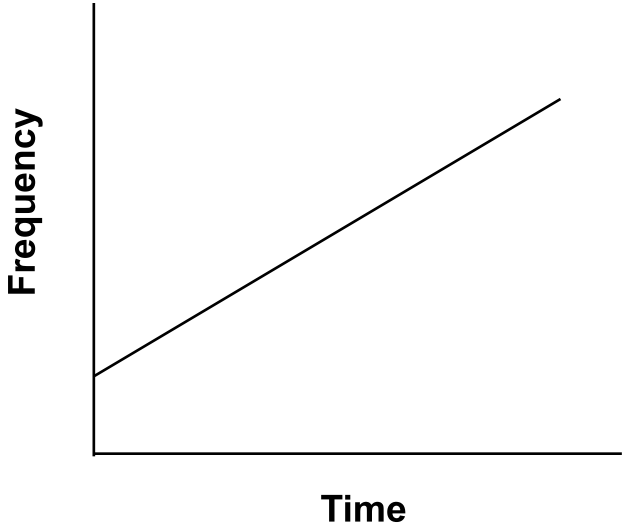
Pulse at single frequency





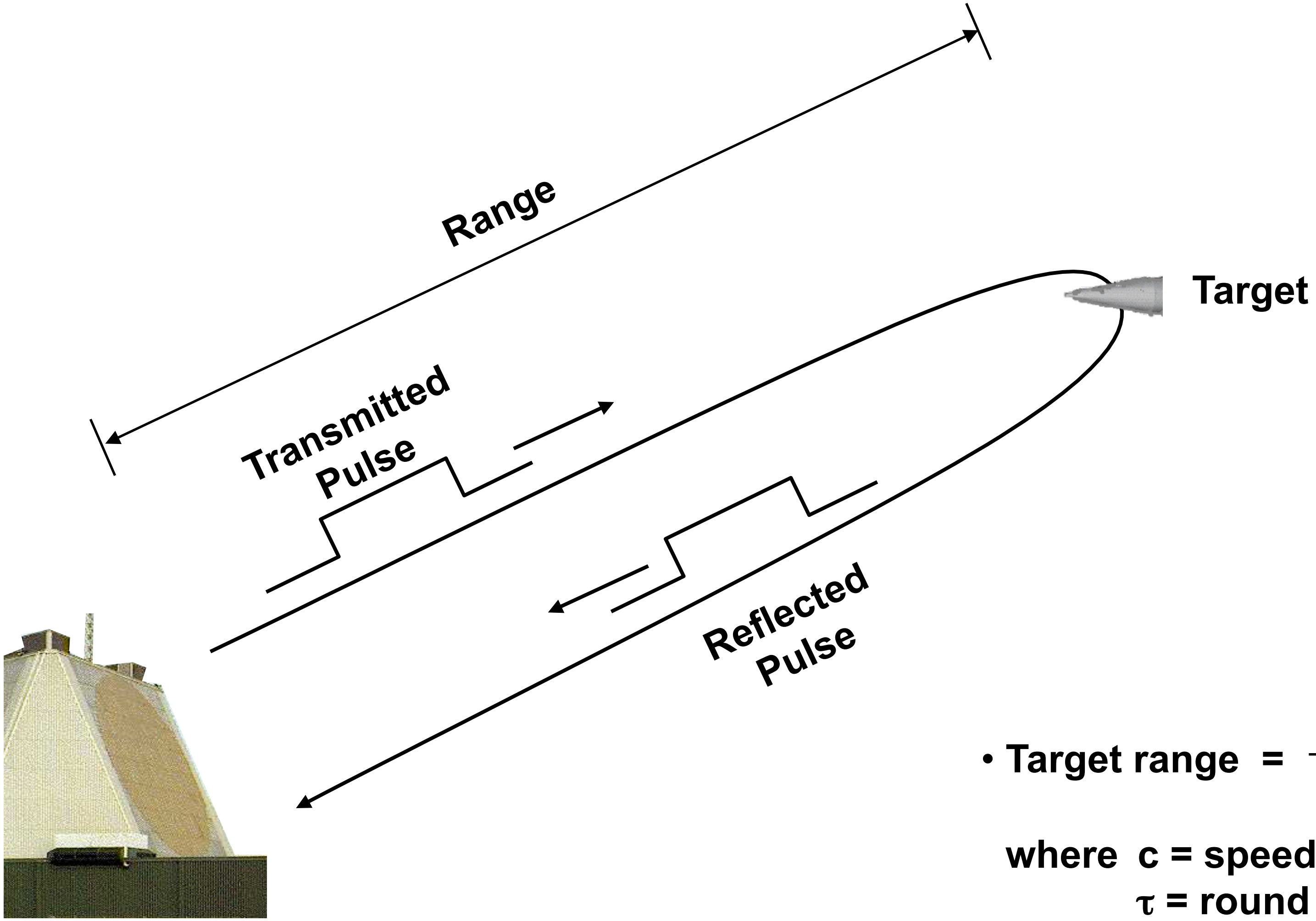
Pulse with changing frequency





Linear Frequency-Modulated (LFM) Waveform

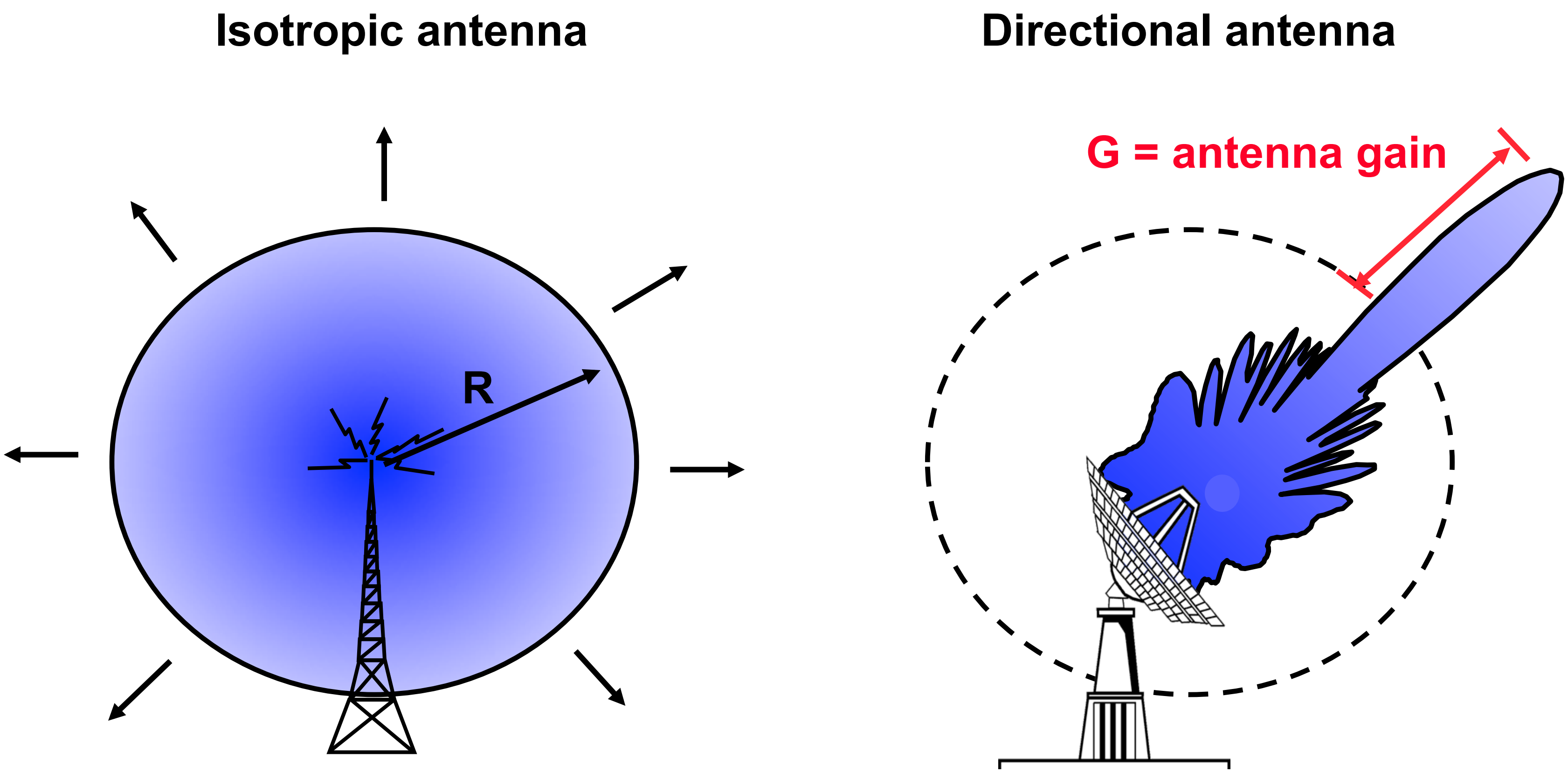
Radar Range Measurement



- Target range $= \frac{c\tau}{2}$

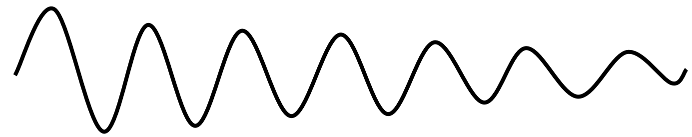
  where c = speed of light
  τ = round trip time

Antenna Gain

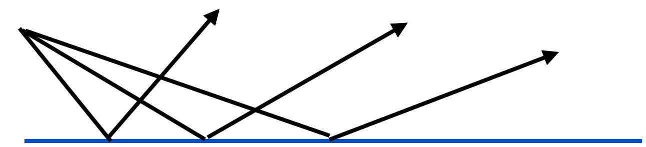


Propagation Effects on Radar Performance

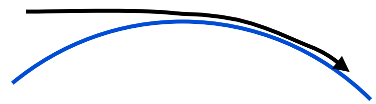
- **Atmospheric attenuation**



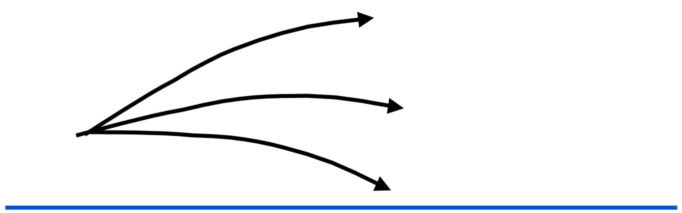
- **Reflection off of earth's surface**



- **Over-the-horizon diffraction**

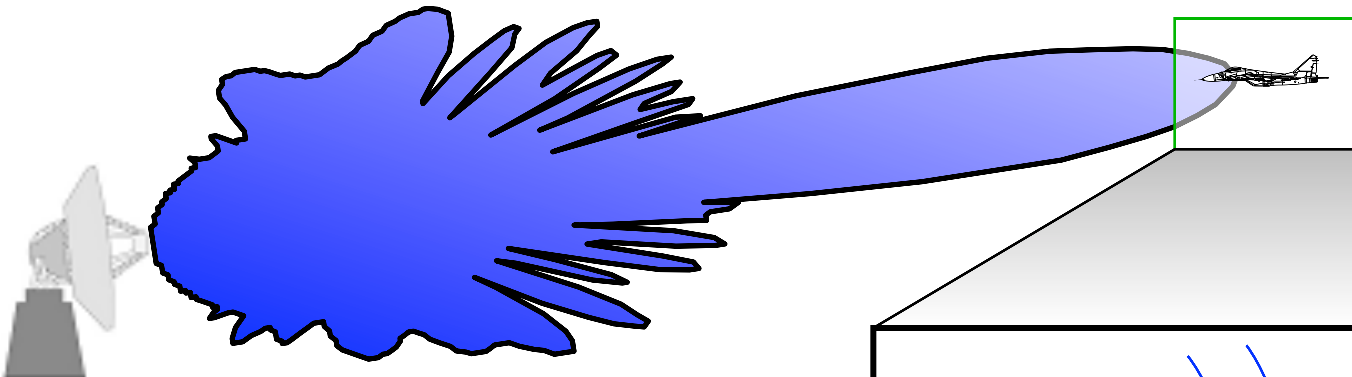


- **Atmospheric refraction**



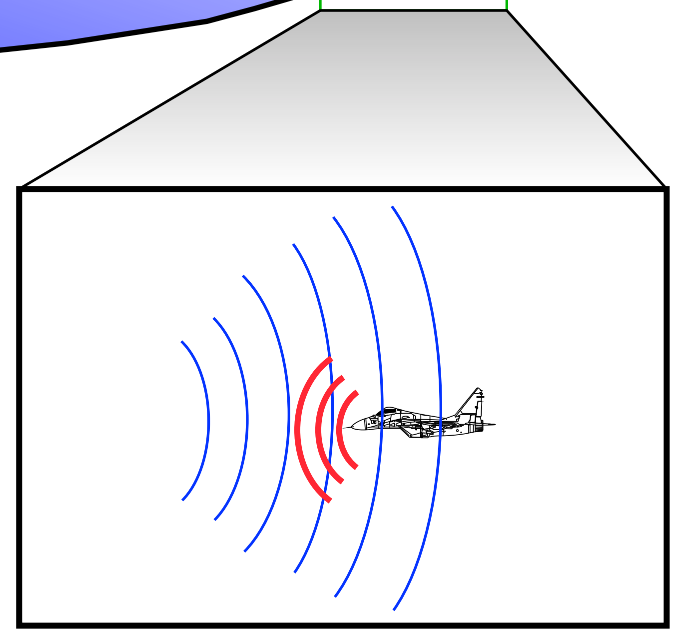
Radar beams can be attenuated, reflected and bent by the environment

Radar Cross Section (RCS)



RCS

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



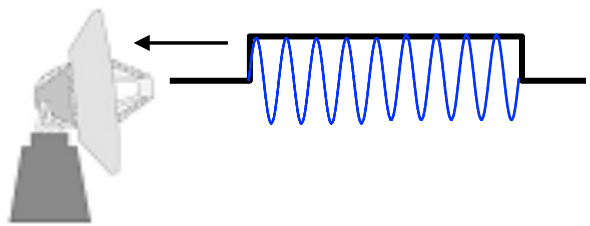
Radar Cross Section (RCS, or s) is the *effective* cross-sectional area of the target as seen by the radar

measured in m^2, or dBm^2

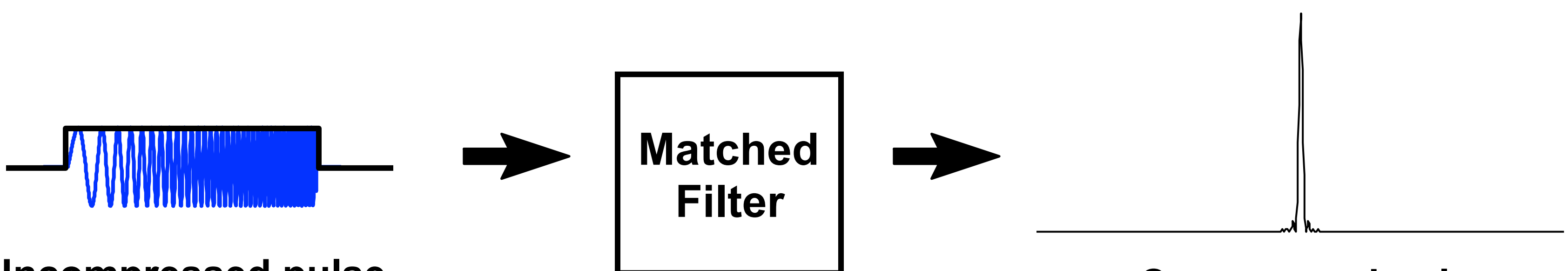
Signal Processing
Pulse Compression

Problem: Pulse can be very long; does not allow accurate range measurement

$$\underbrace{1\ \text{msec}}\ \times\ \frac{c}{2} = 150\ \text{km}$$



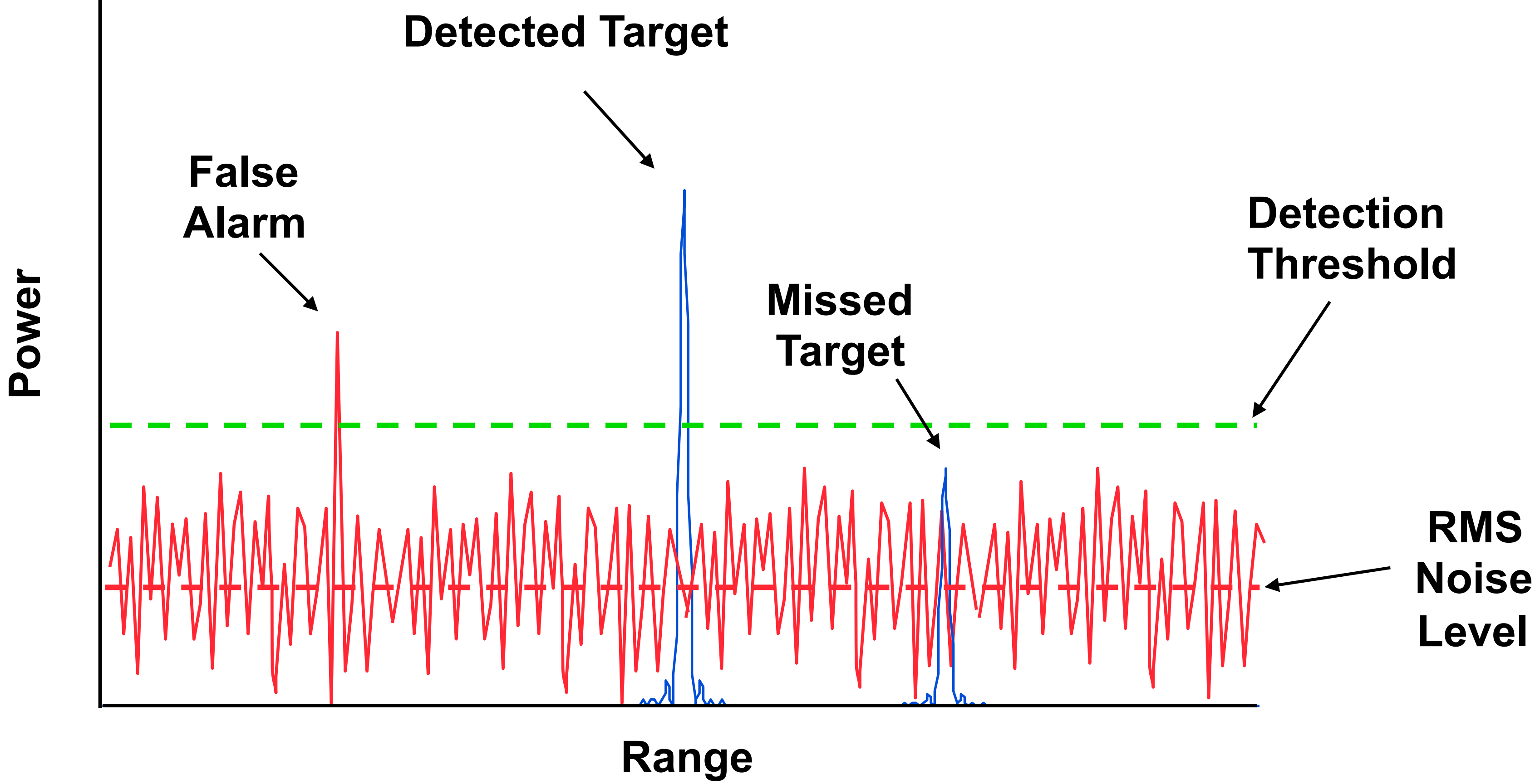
Solution: Use pulse with changing frequency and signal process using "matched filter"



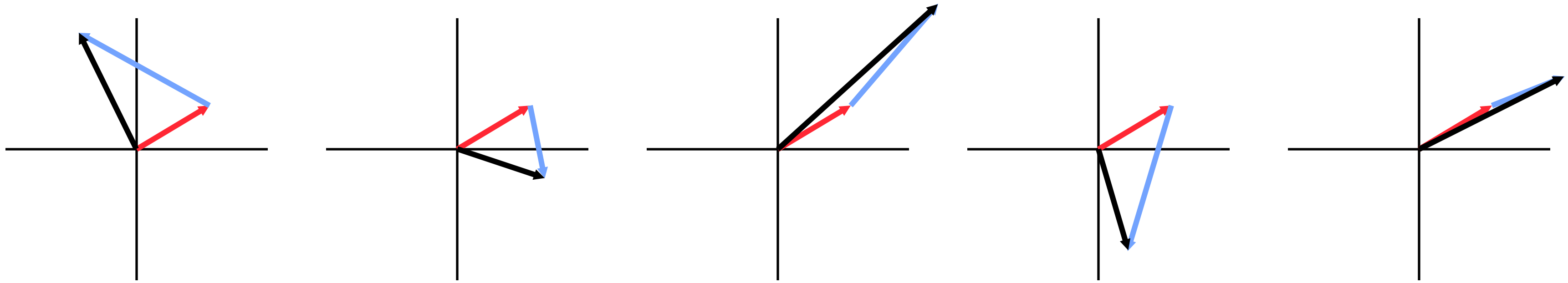
Uncompressed pulse

Compressed pulse

Detection of Signals in Noise



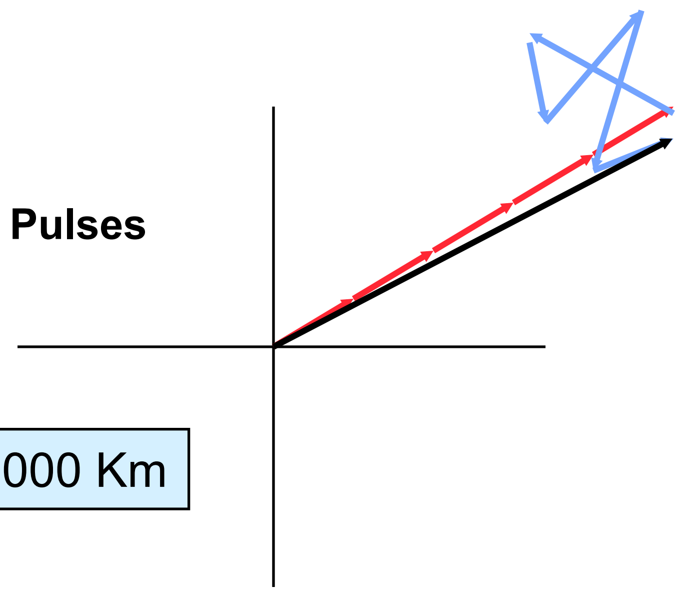
Coherent Integration



Pulse 1 Pulse 2 Pulse 3 Pulse 4 Pulse 5

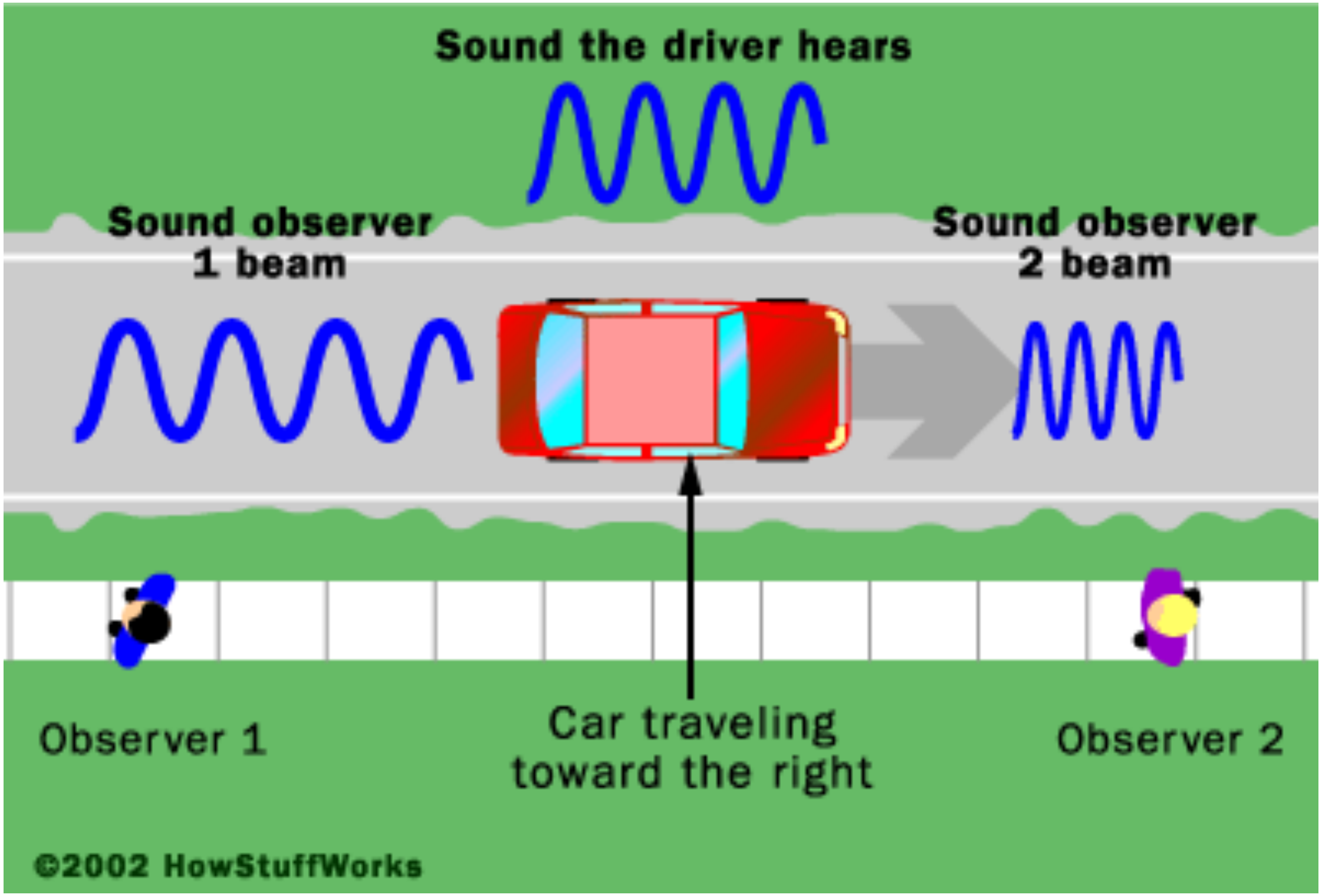
- Coherent target returns
- Noise samples at low SNR
- Resultant signal

Coherently Integrated Pulses

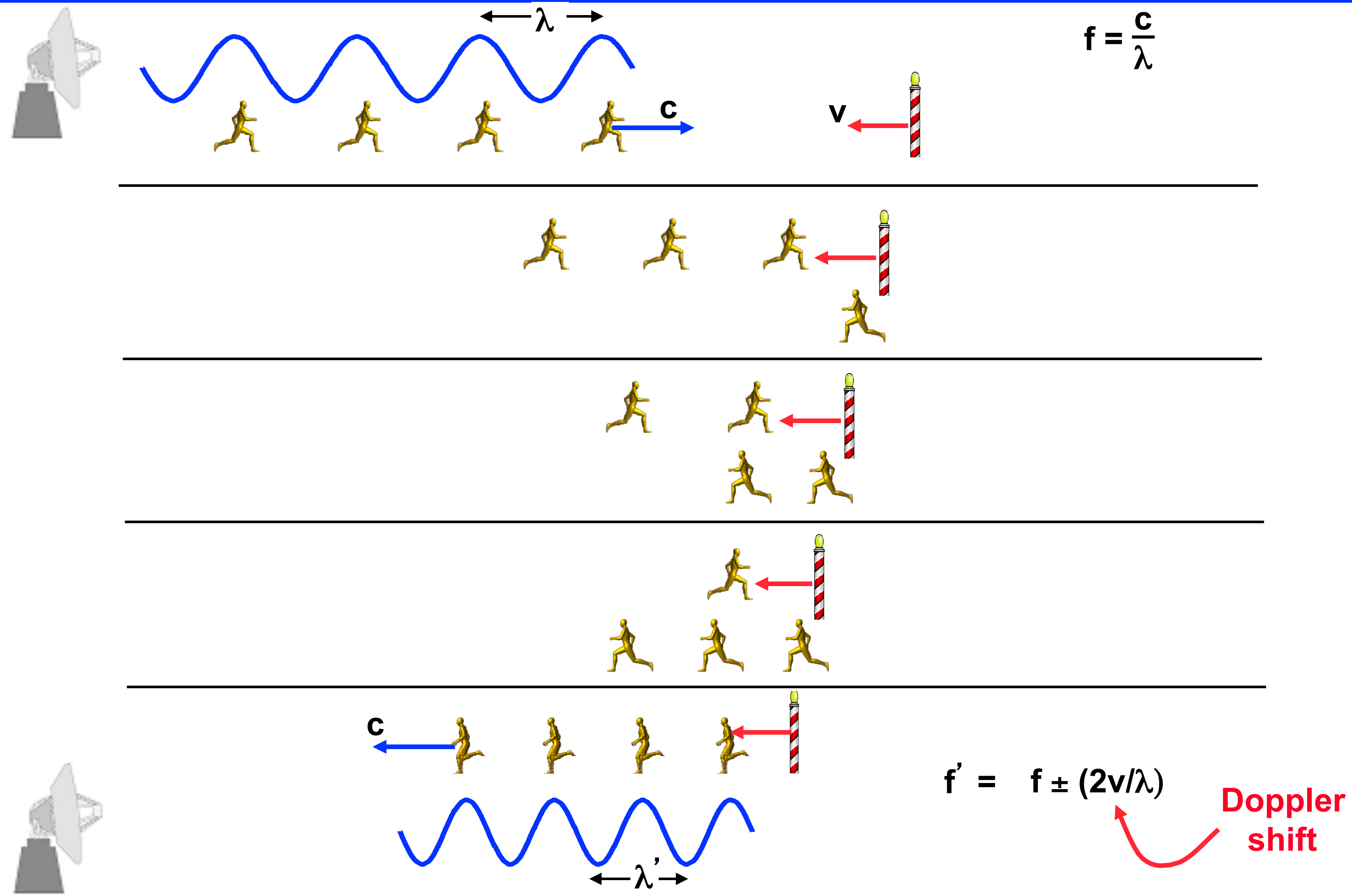


Deep space targets at 30,000 – 40,000 Km

Doppler Effect



Doppler Shift Concept



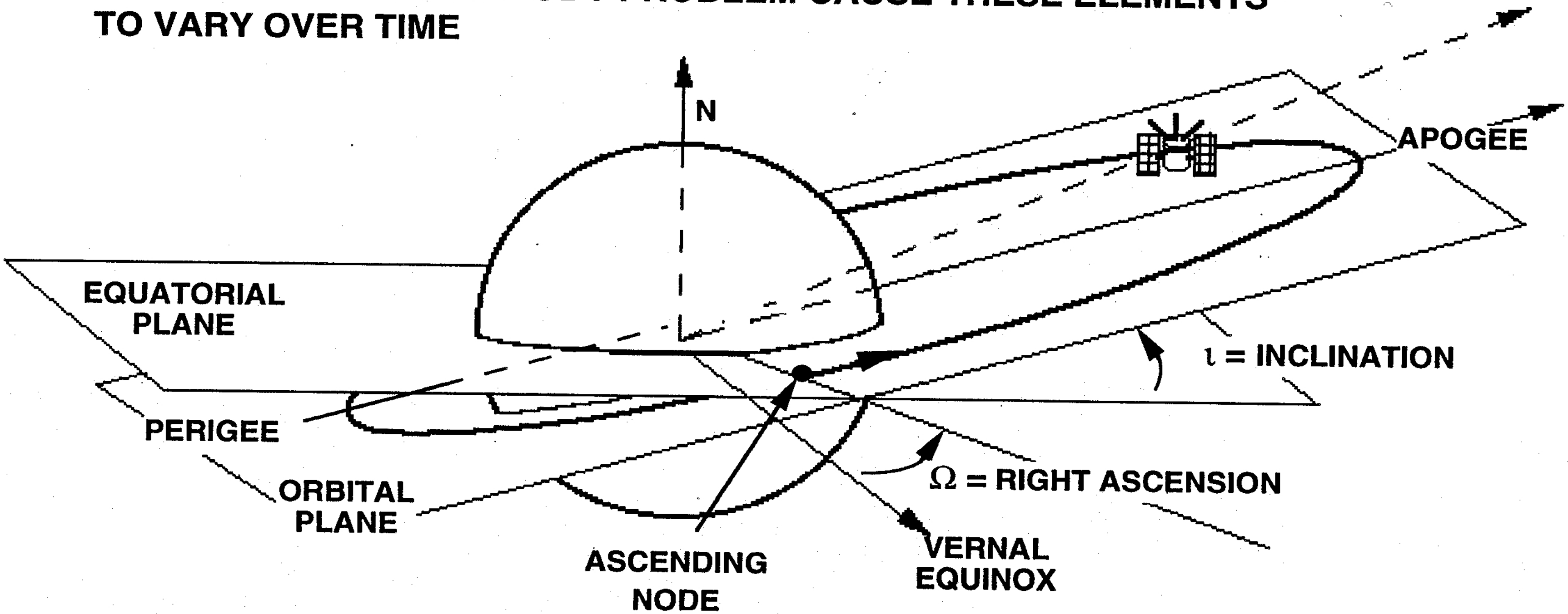
Outline

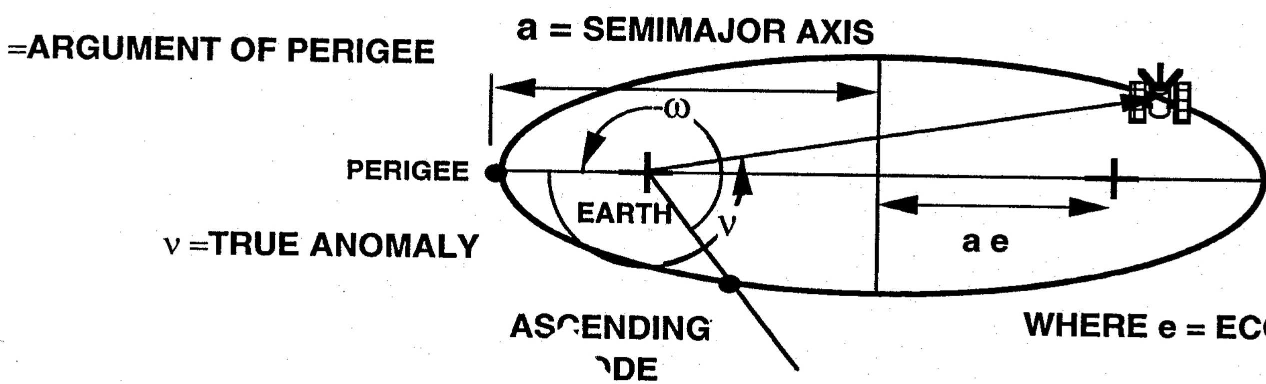
- Introduction
  - Movie
  - QUIZ !!!
- History
- The basics
  - Radar
  - Satellite Tracking

SATELLITE ORBITAL MECHANICS

SATELLITE ORBIT DESCRIBED BY KEPLERIAN ELEMENT SET (ι, Ω, e, ω, M, a, T)

PERTURBATIONS TO 2-BODY PROBLEM CAUSE THESE ELEMENTS TO VARY OVER TIME



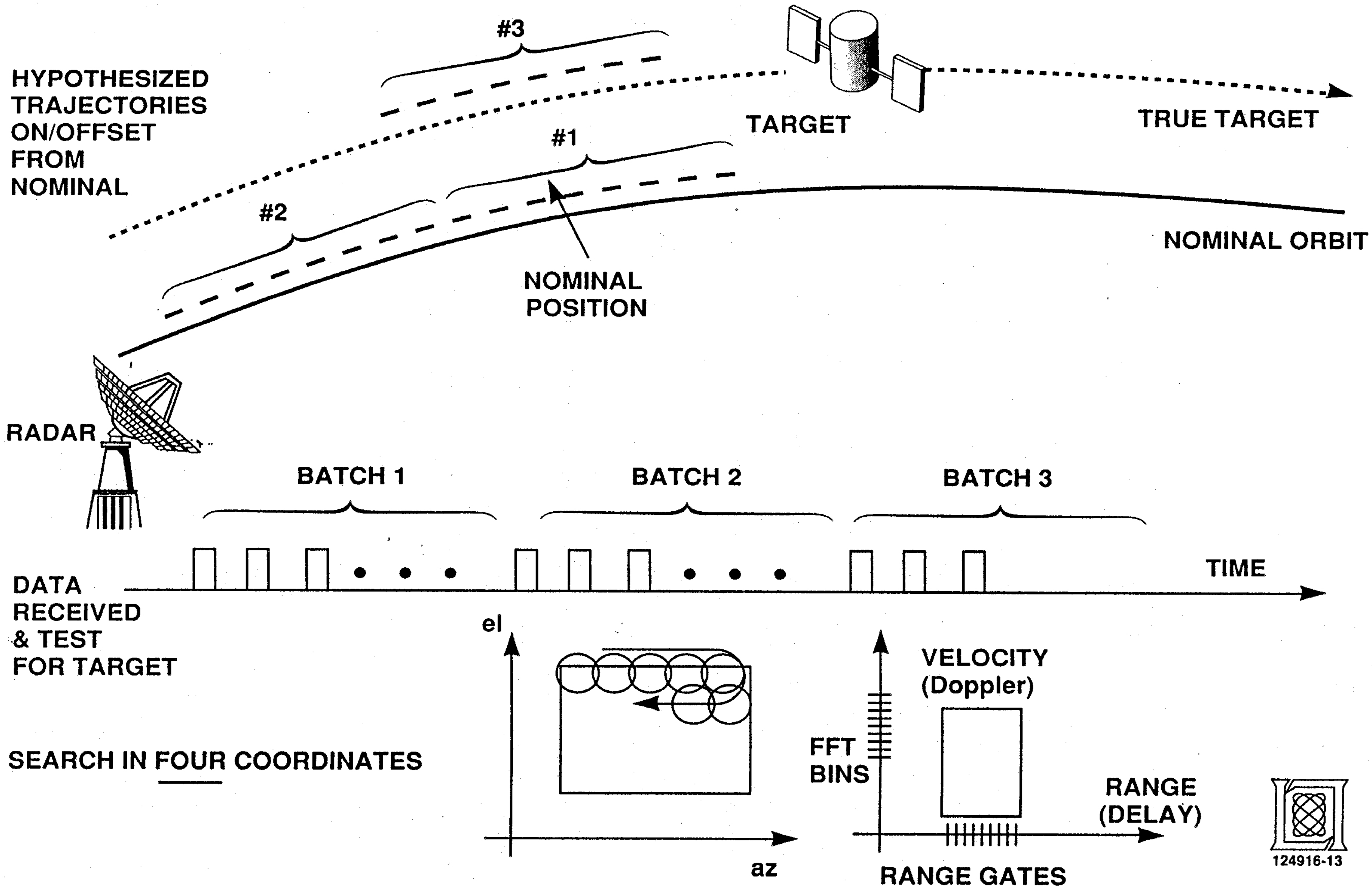


TRUE ANOMALY ν IS REPLACED BY MEAN ANOMALY M

T IS EPOCH

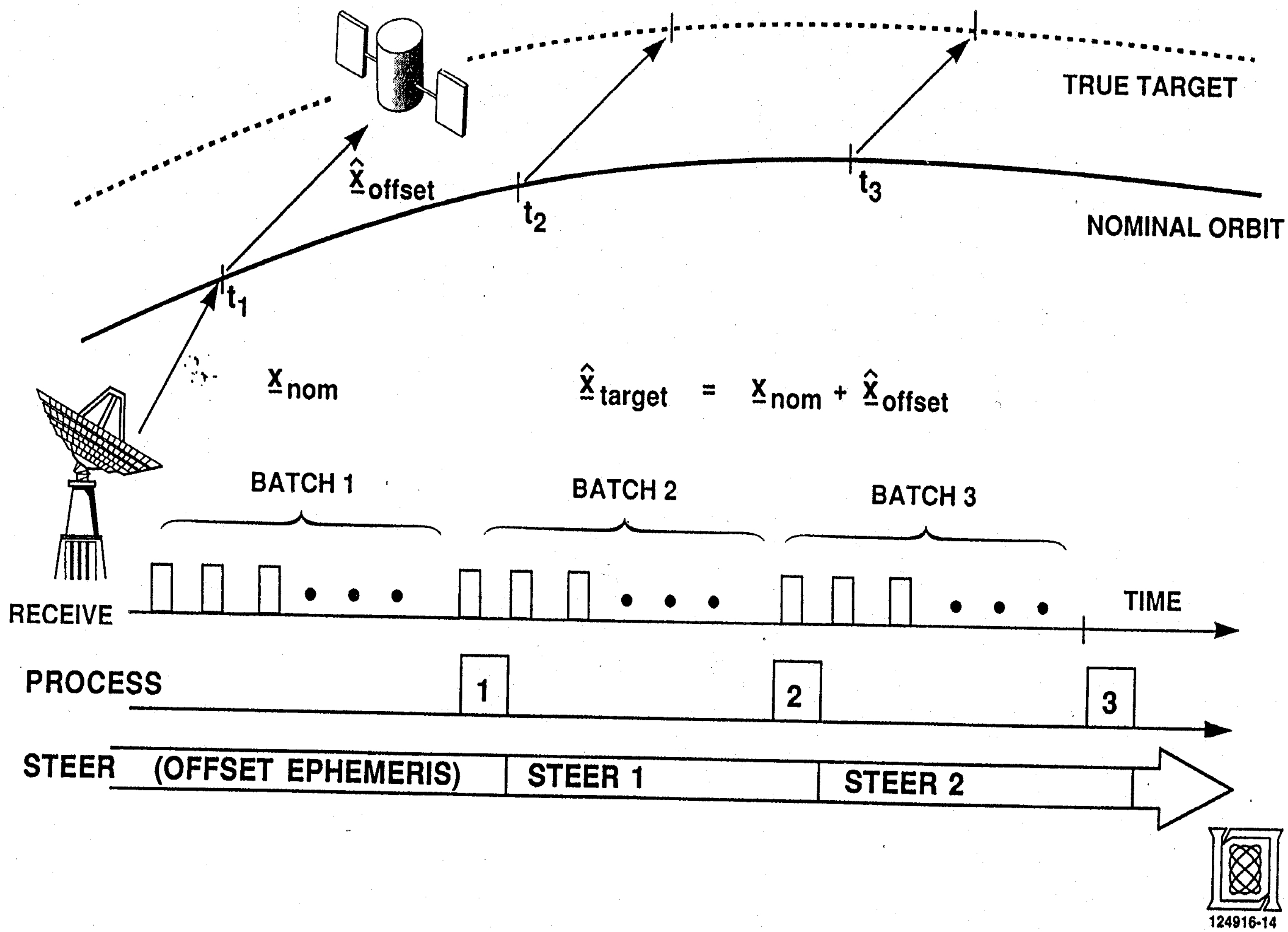
WHERE e = ECCENTRICITY

EPHEMERIS-GUIDED SEARCH

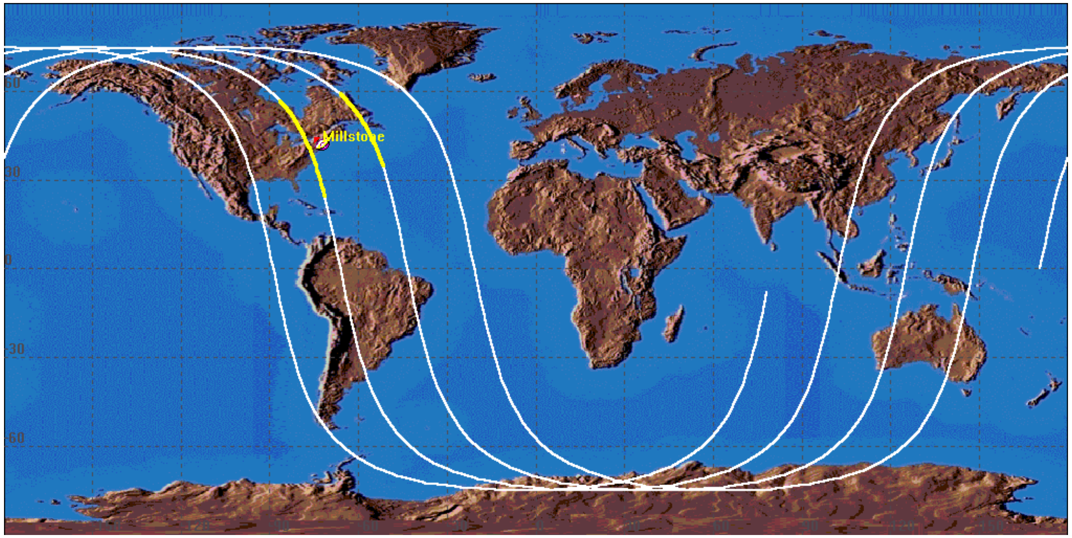


SEARCH IN FOUR COORDINATES

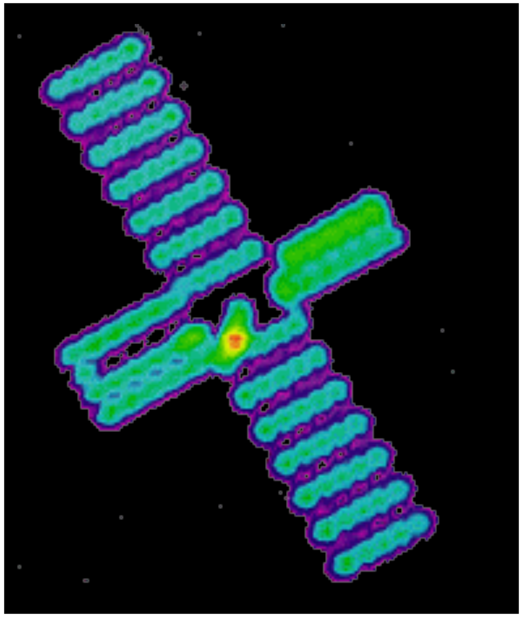
EPHEMERIS-GUIDED TRACK



Space Surveillance Data Products

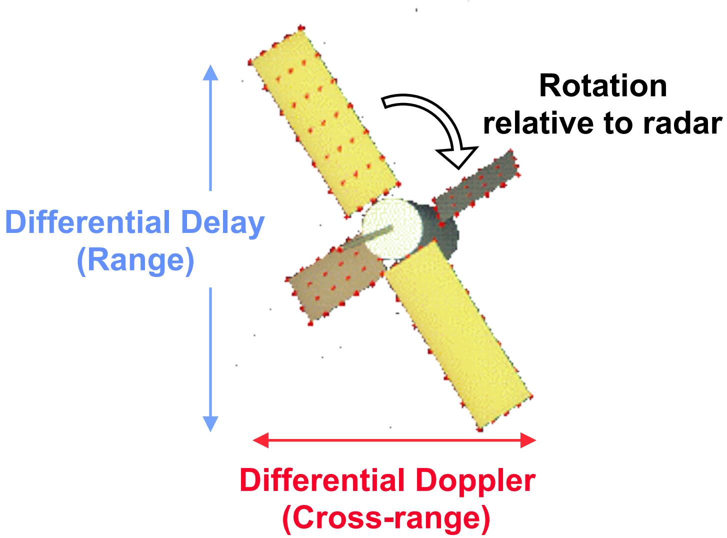


- Where is it?
  - Metric data gives orbital position

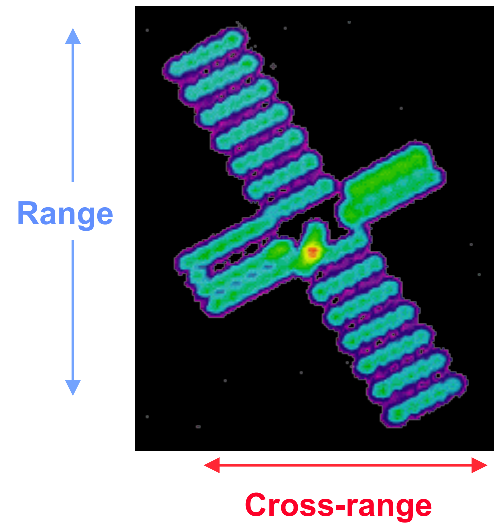


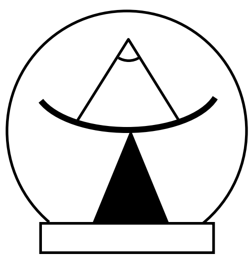
- What is it?
  - Image analysis gives size and shape
- What is it doing?
  - Motion analysis gives attitude

Radar Imaging of Spacecraft



Simulated Radar Image





Characteristics:

Available on-demand
- all weather
- day and night

Resolution independent of range

Benefits:

Shape / Size Estimate
Operational Mode Determination
Launch/Status Monitoring
Damage Assessment
Motion Determination