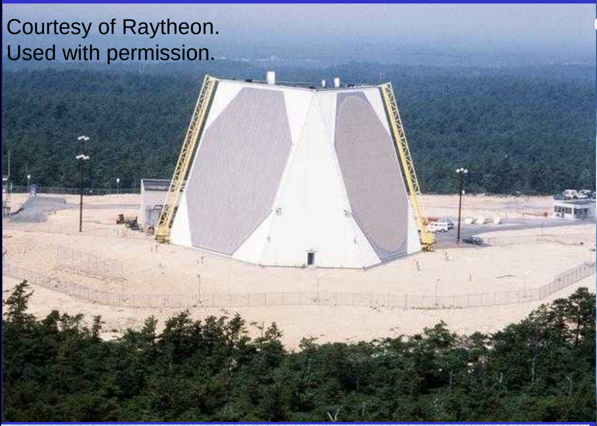
Outline

- **Why radar?**
- **The basics**

Means of Sensing

	Optical/IR	Radar	Acoustic	Other
Applications	• Ground surveillance/ reconnaissance/ID • Laser targeting • Night vision • Space surveillance • Missile seekers	• Surveillance • Tracking • Fire control • Target ID/ discrimination • Ground surveillance/ reconnaissance • Ground mapping • Moving target detection • Air traffic control • Missile seekers	• Sonar • Blast detection • Troop movement detection	• Chem/Bio • Radiological
Attributes		• Long range • All-weather • Day/night • 3-space target location • Reasonably robust against countermeasures		

Surveillance and Fire Control Radars


Courtesy of Raytheon. Used with permission.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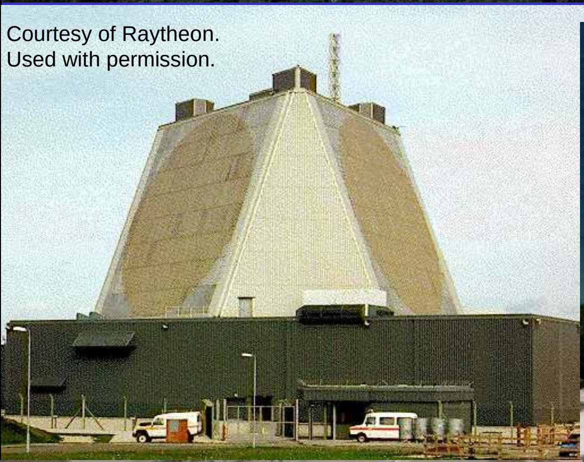
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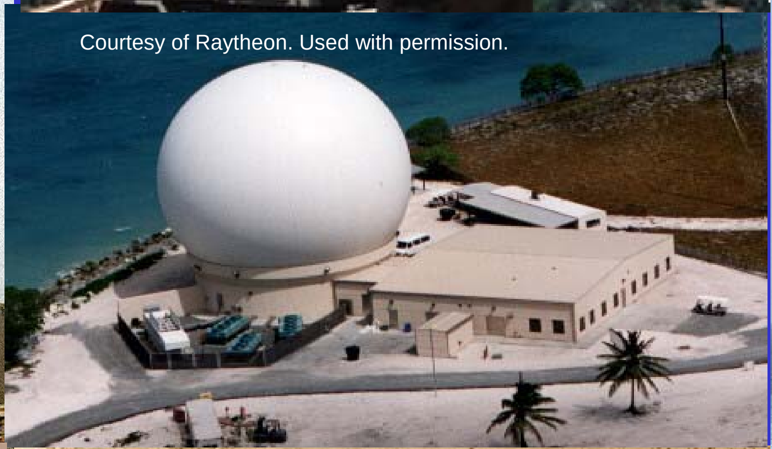
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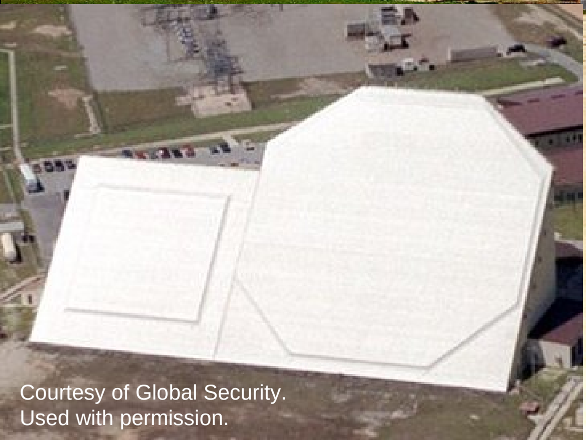
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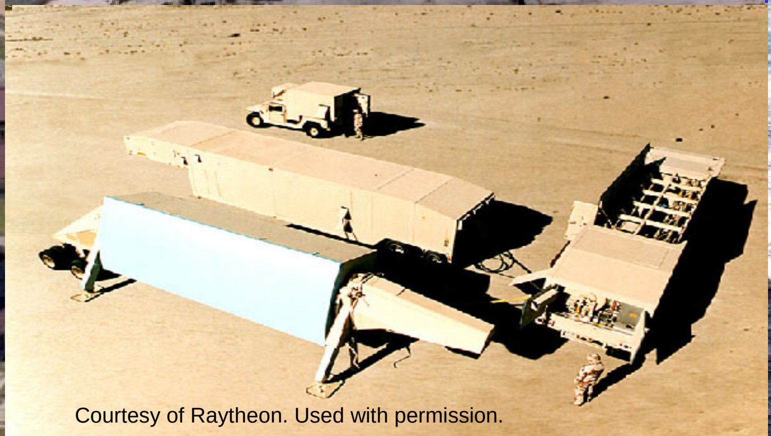
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Airborne and Air Traffic Control Radars


Courtesy Lincoln Laboratory.

Courtesy of US Air Force.

Courtesy of US Navy.


Courtesy of Northrop Grumman.
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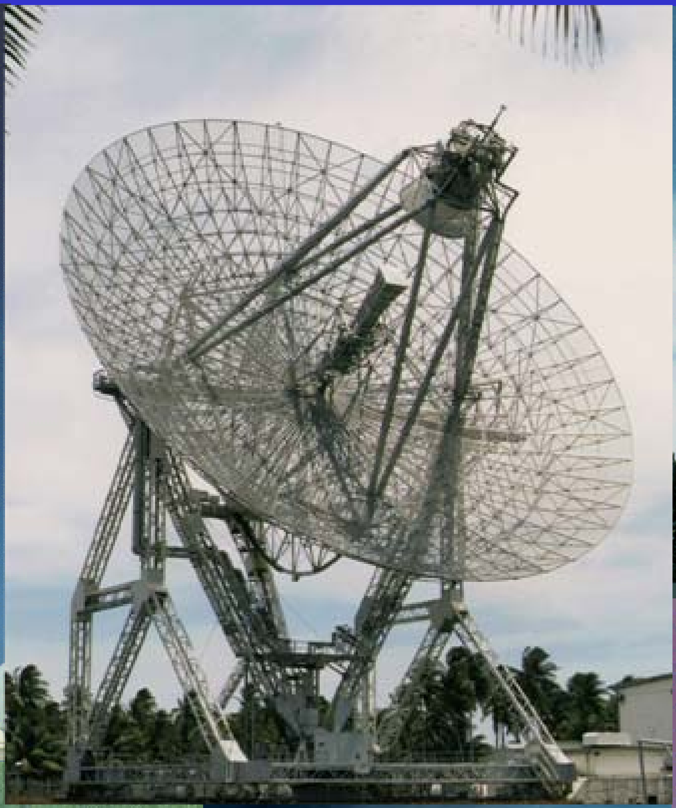
Courtesy of US Air Force.

Courtesy of US Air Force.

Instrumentation Radars

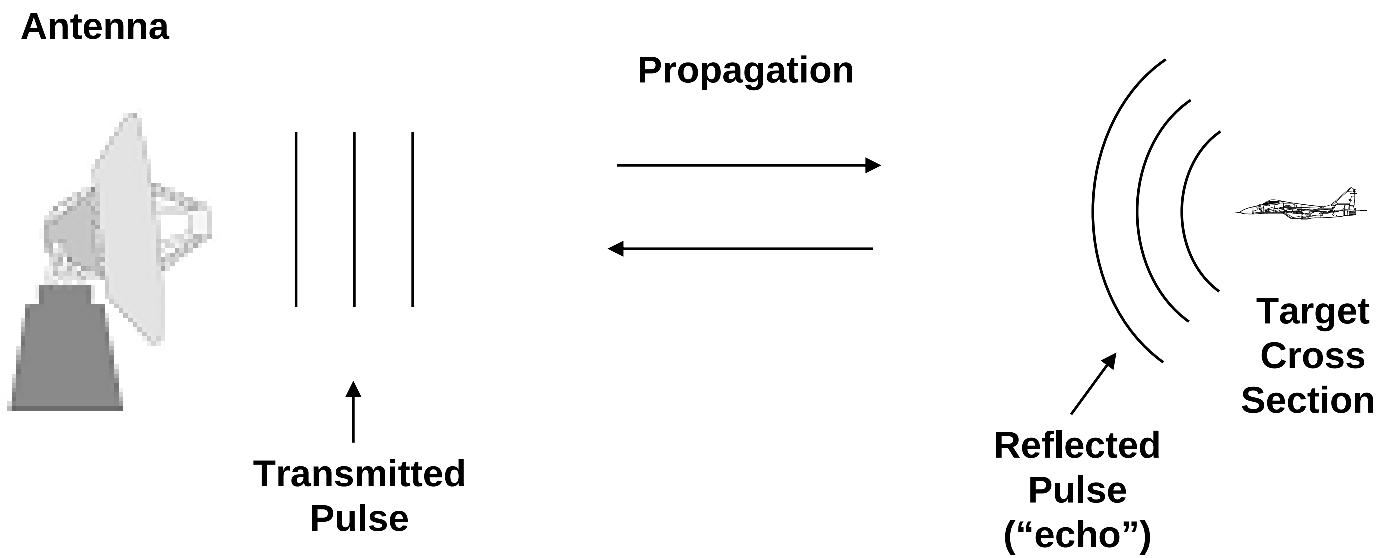


Outline

- **Why radar?**
- **The basics**

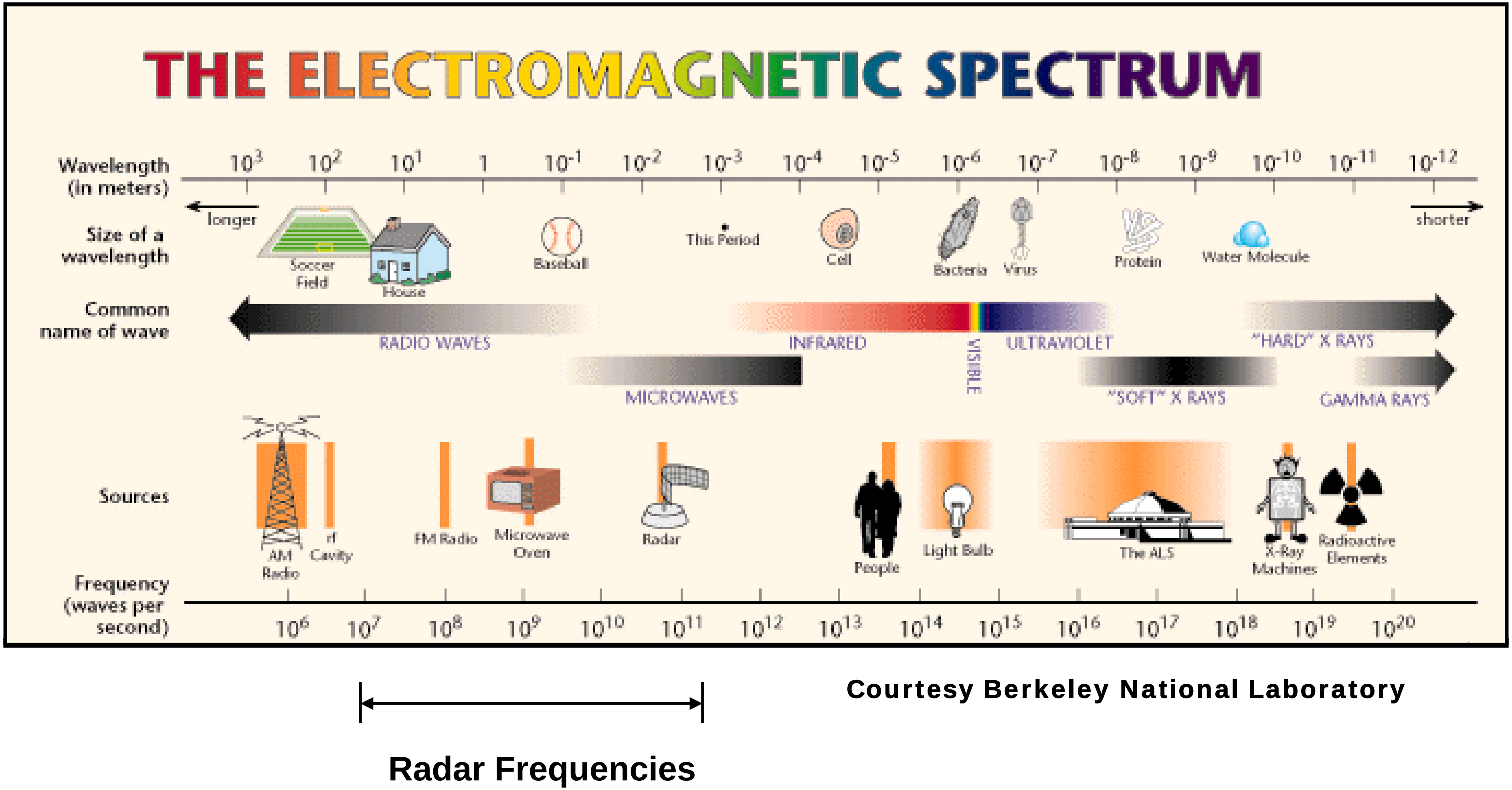
RADAR

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



Courtesy Berkeley National Laboratory

Properties of Waves
Relationship Between Frequency and Wavelength

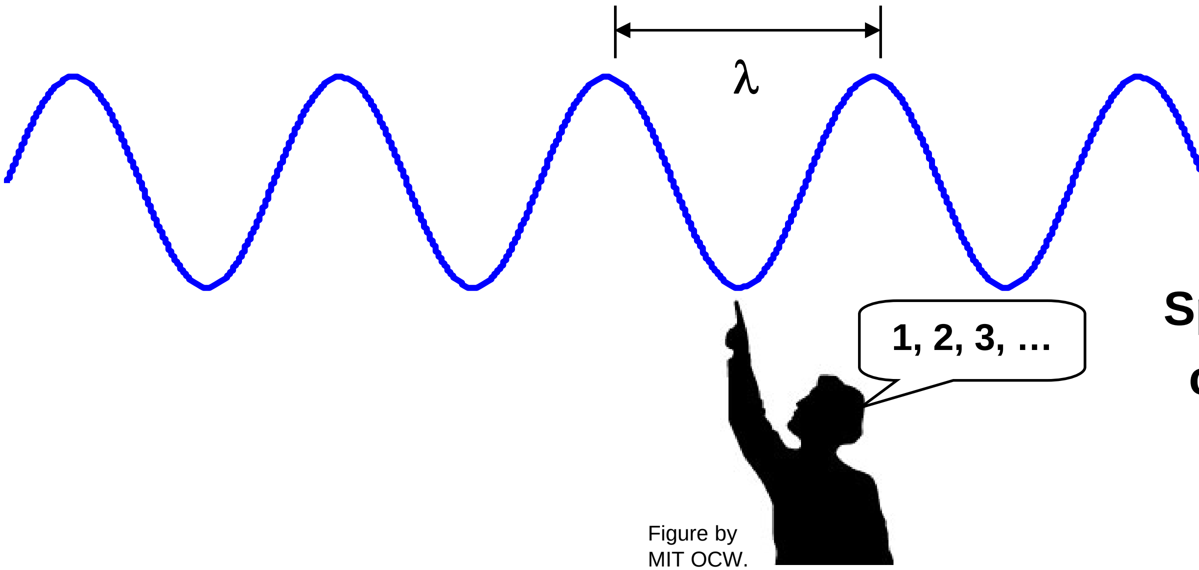


Figure by MIT OCW.

Speed of light, c

$c = 3 \times 10^8$ m/sec

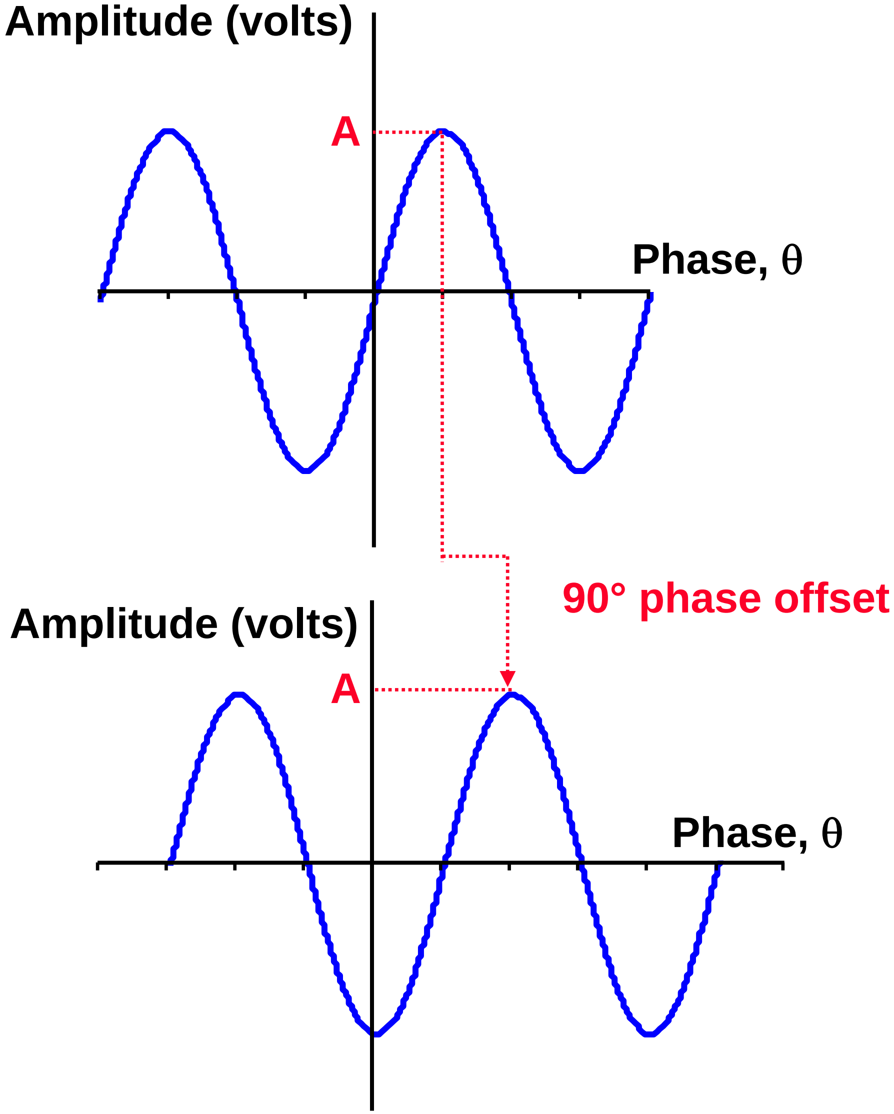
$= 300{,}000{,}000$ m/sec

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

Examples:

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

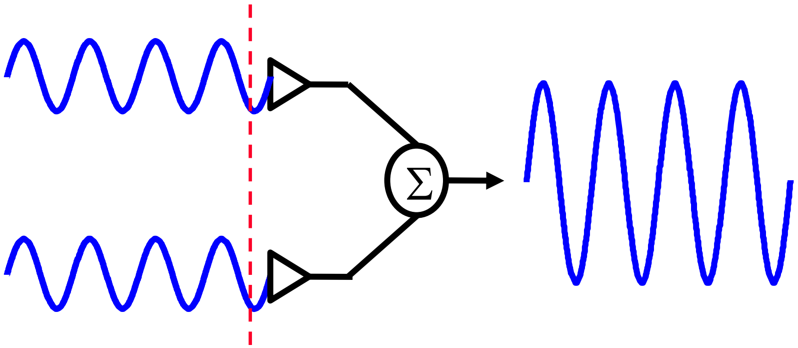
Properties of Waves
Phase and Amplitude



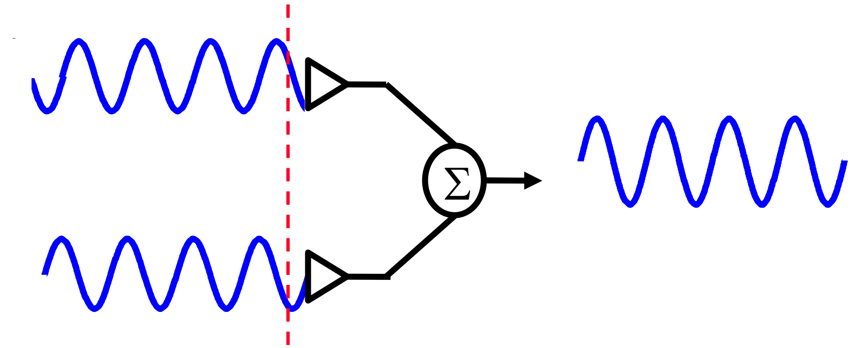
$A \sin(\theta)$

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

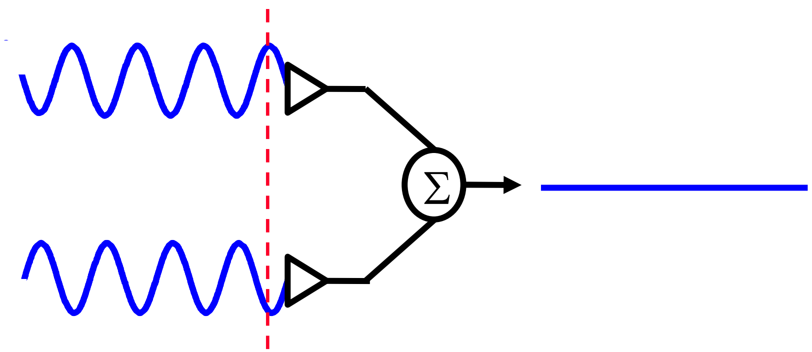
Properties of Waves
Constructive vs. Destructive Addition



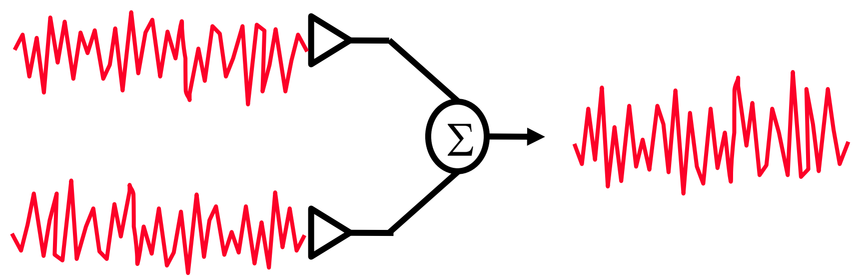
Constructive
(in phase)



Partially Constructive
(somewhat out of phase)



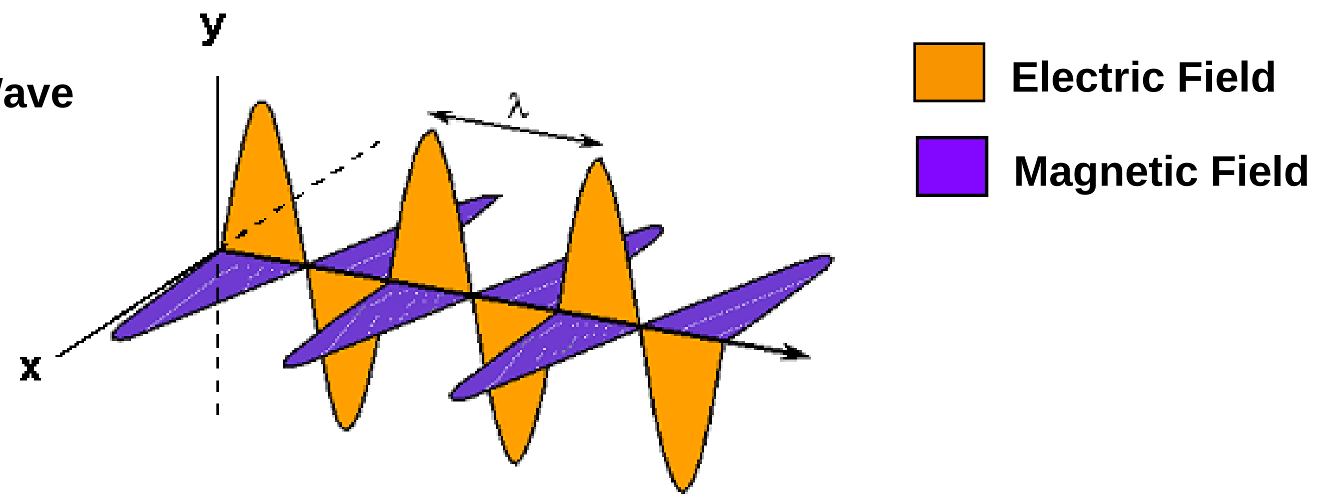
Destructive
(180° out of phase)



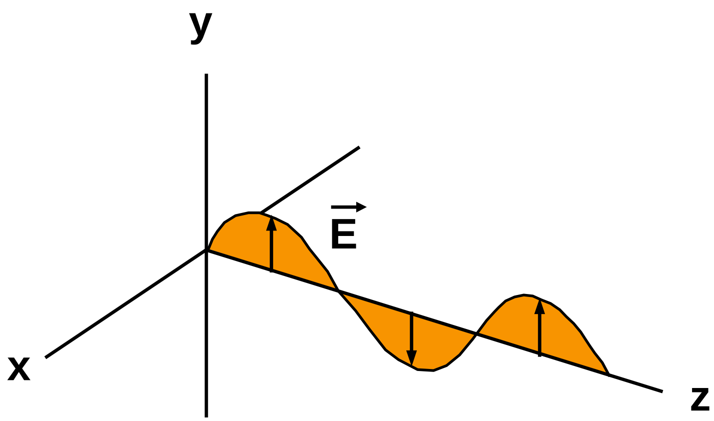
Non-coherent signals
(noise)

Polarization

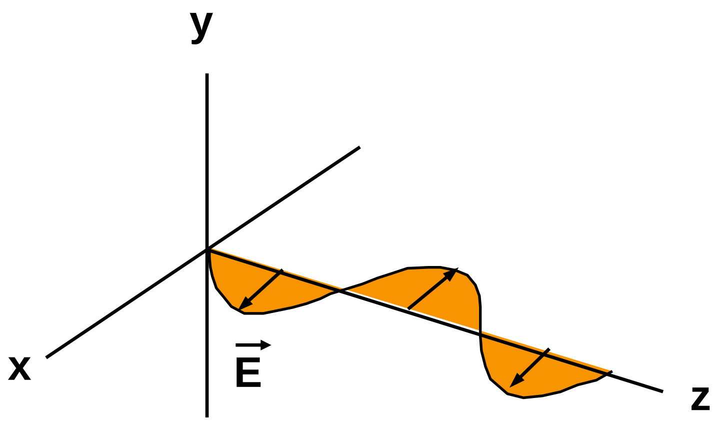
Electromagnetic Wave



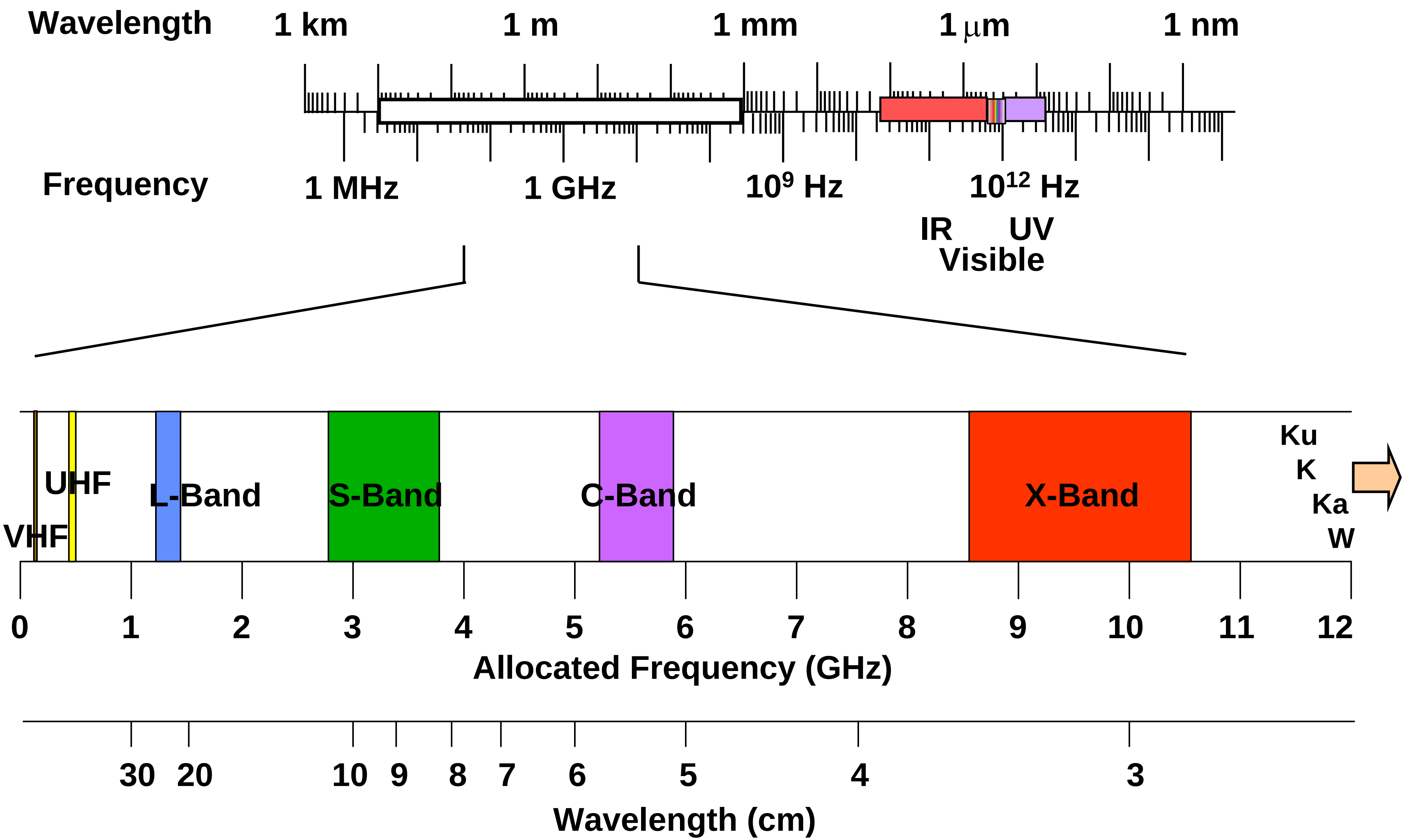
Vertical Polarization



Horizontal Polarization



Radar Frequency Bands



IEEE Standard Radar Bands
(Typical Use)

HF	3 – 30 MHz
VHF	30 MHz–300 MHz
UHF	300 MHz–1 GHz
L-Band	1 GHz–2 GHz
S-Band	2 GHz–4 GHz
C-Band	4 GHz–8 GHz
X-Band	8 GHz–12 GHz
Ku-Band	12 GHz–18 GHz
K-Band	18 GHz–27 GHz
Ka-Band	27 GHz–40 GHz
W-Band	40 GHz – 100+ GHz

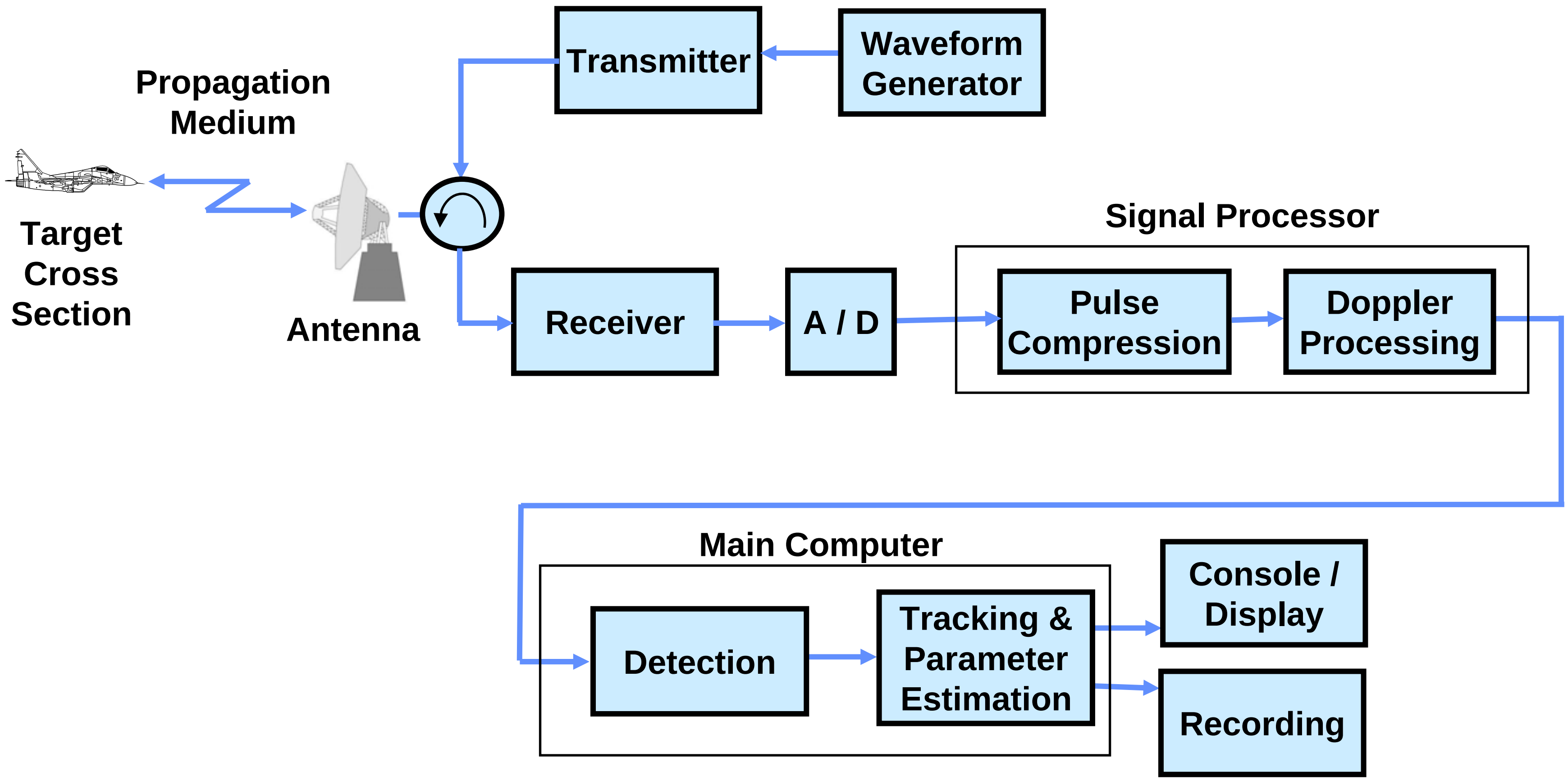
Search Radars

Search & Track Radars

Fire Control & Imaging Radars

Missile Seekers

Radar Block Diagram



Radar Range Equation

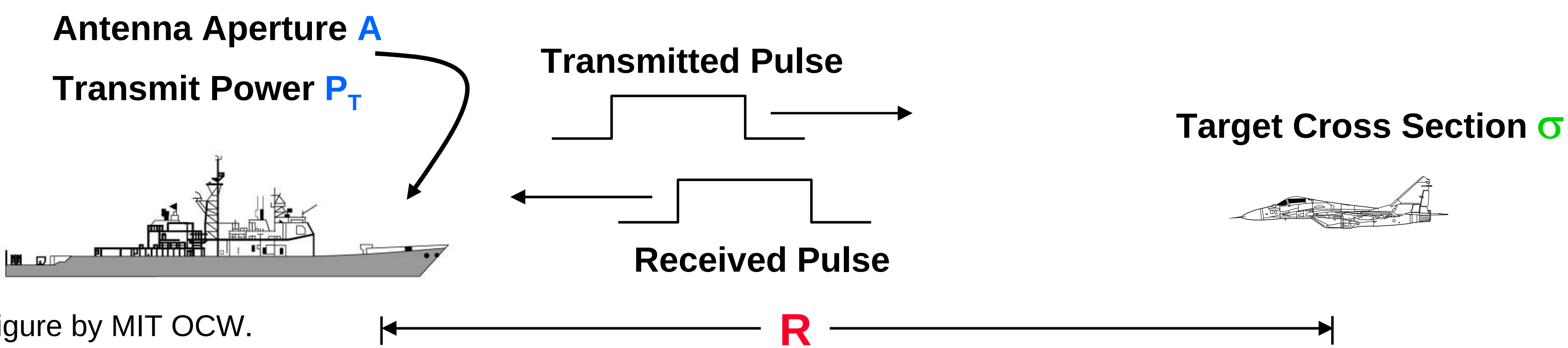
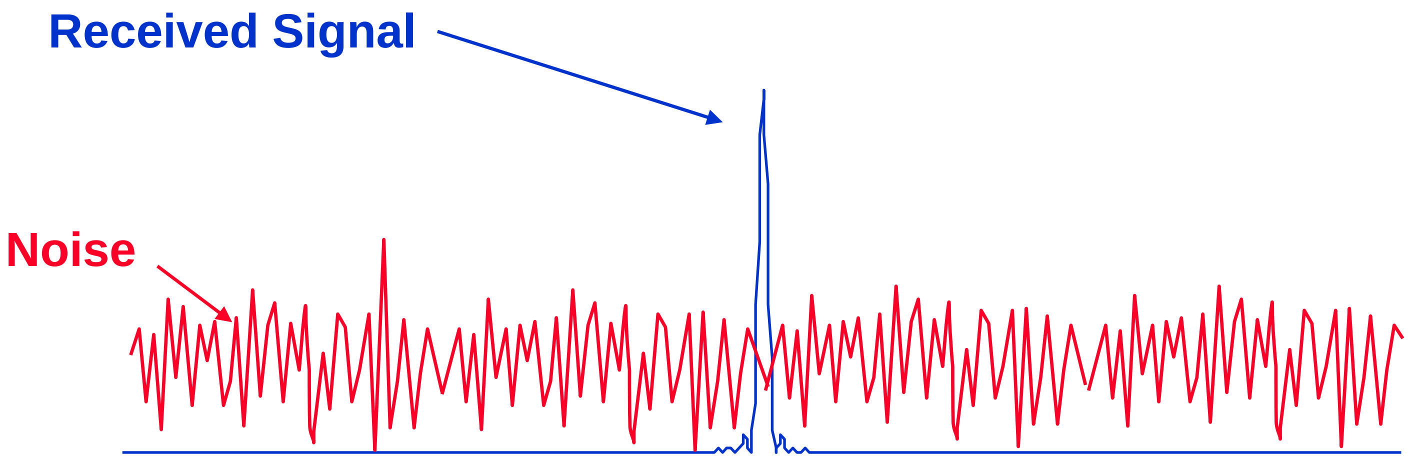


Figure by MIT OCW.

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

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

Signal-to-Noise Ratio



$$\text{SNR} = \frac{\text{Received Signal Energy}}{\text{Noise Energy}}$$

What the #@!*% is a dB?

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

Example:

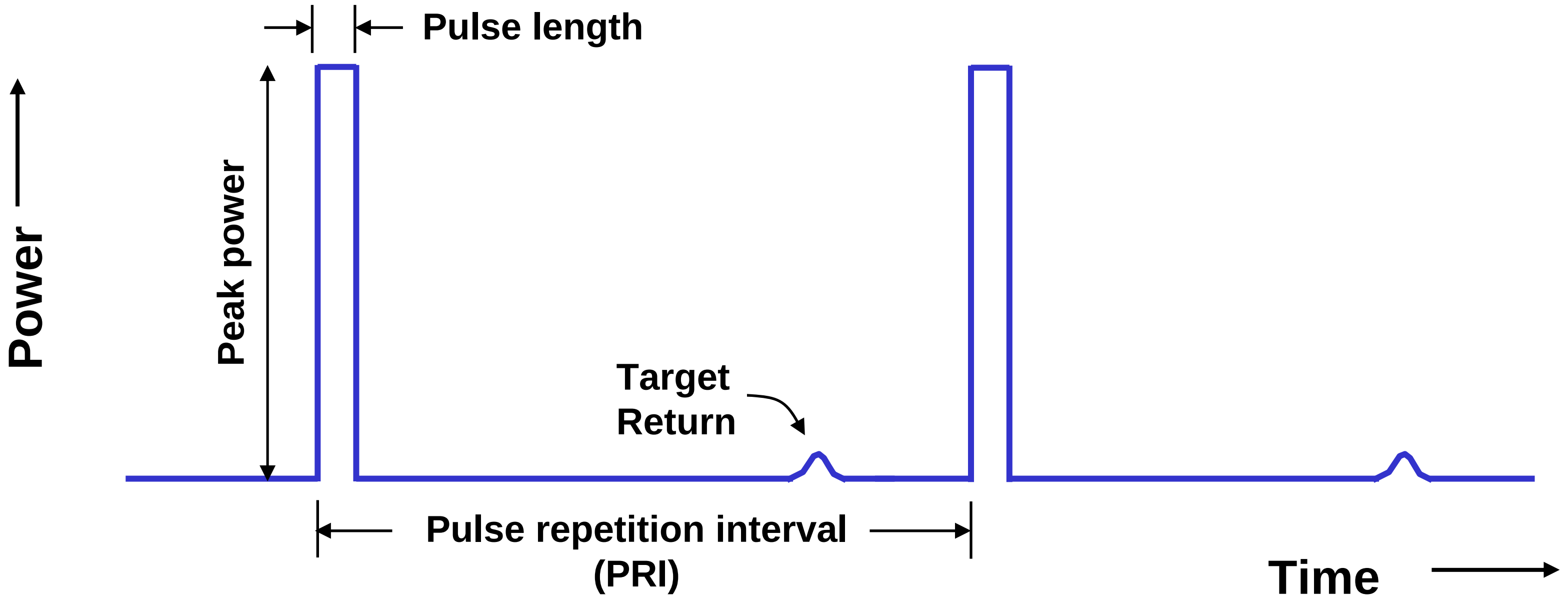
$$\text{Signal-to-noise ratio (dB)} = 10 \log_{10} \left[\frac{\text{Signal Power}}{\text{Noise Power}} \right]$$

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



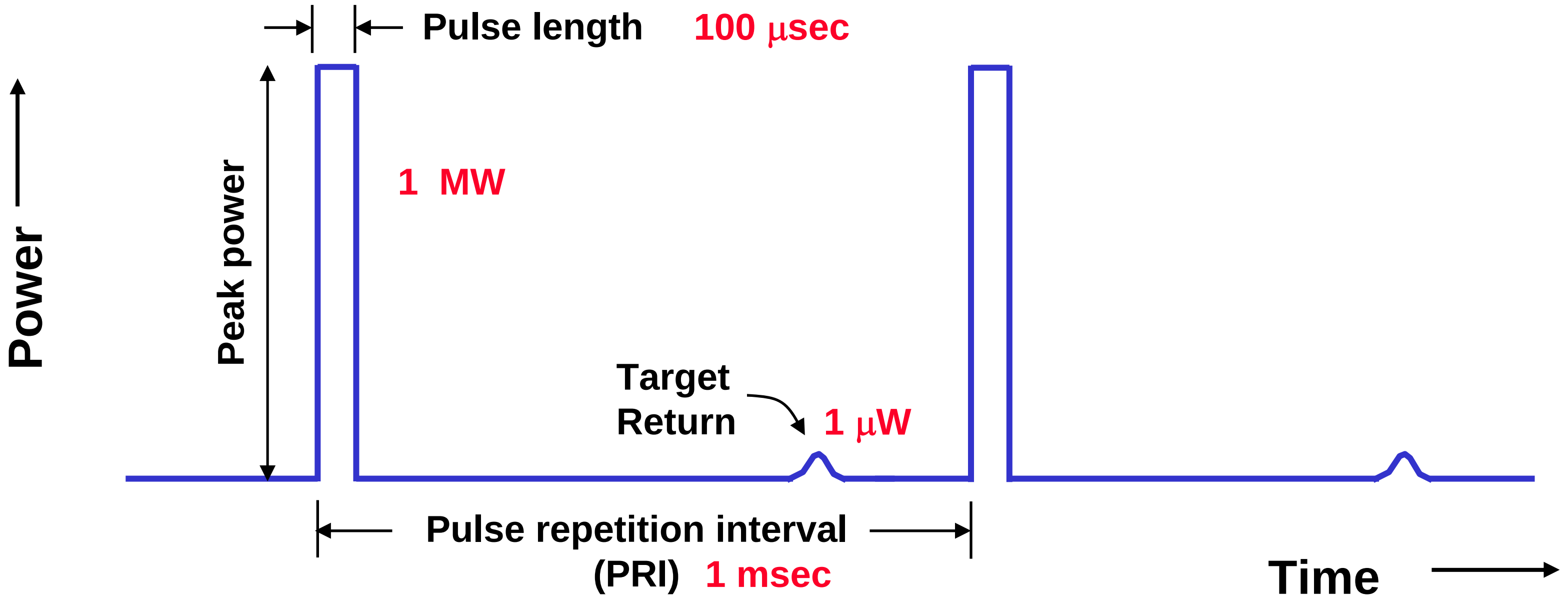
$$\text{Duty cycle} = \frac{\text{Pulse length}}{\text{Pulse repetition interval}}$$

Average power = Peak power * Duty cycle

Pulse repetition frequency (PRF) = 1/(PRI)

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

Pulsed Radar
Terminology and Concepts



Duty cycle = $\frac{\text{Pulse length}}{\text{Pulse repetition interval}}$ 10%

Average power = Peak power * Duty cycle 100 kW

Pulse repetition frequency (PRF) = 1/(PRI) 1 kHz

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

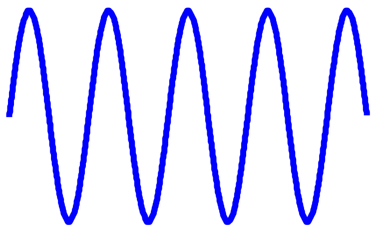
Brief Mathematical Digression
Scientific Notation and Greek Prefixes

Scientific Notation	Standard Notation	Greek Prefix	Radar Examples
10^9	1,000,000,000	Giga	GHz
10^6	1,000,000	Mega	MHz, MW
10^3	1,000	kilo	km
10^1	10	-	-
10^0	1	-	-
10^{-3}	0.001	milli	msec
10^{-6}	0.000,001	micro	μsec

MHz = Megahertz
MW = Megawatt

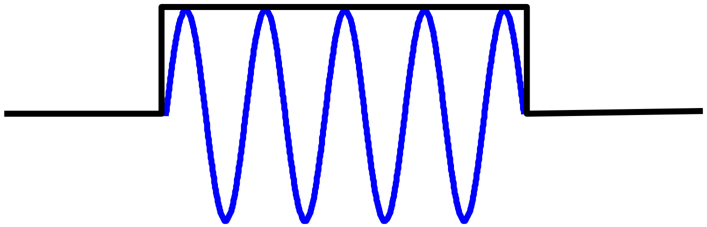
Radar Waveforms

What do radars transmit?



Waves?

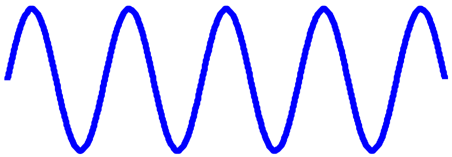
or Pulses?

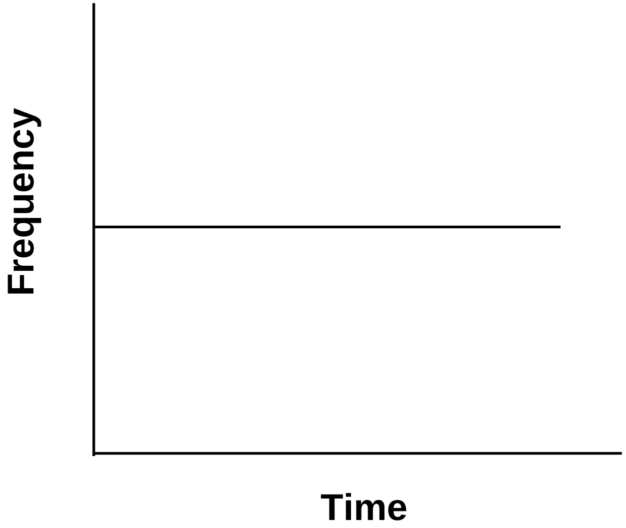


Waves, modulated by "on-off" action of pulse envelope

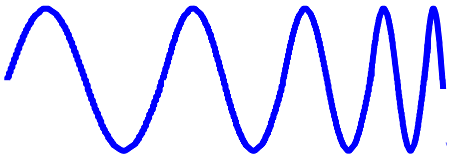
Radar Waveforms (cont'd.)

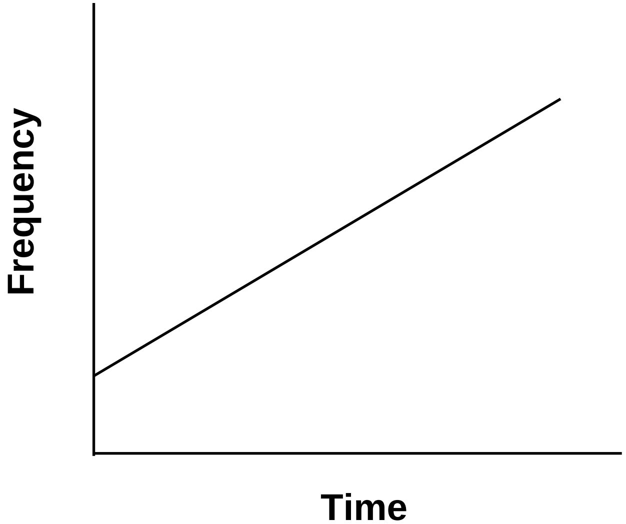
Pulse at single frequency





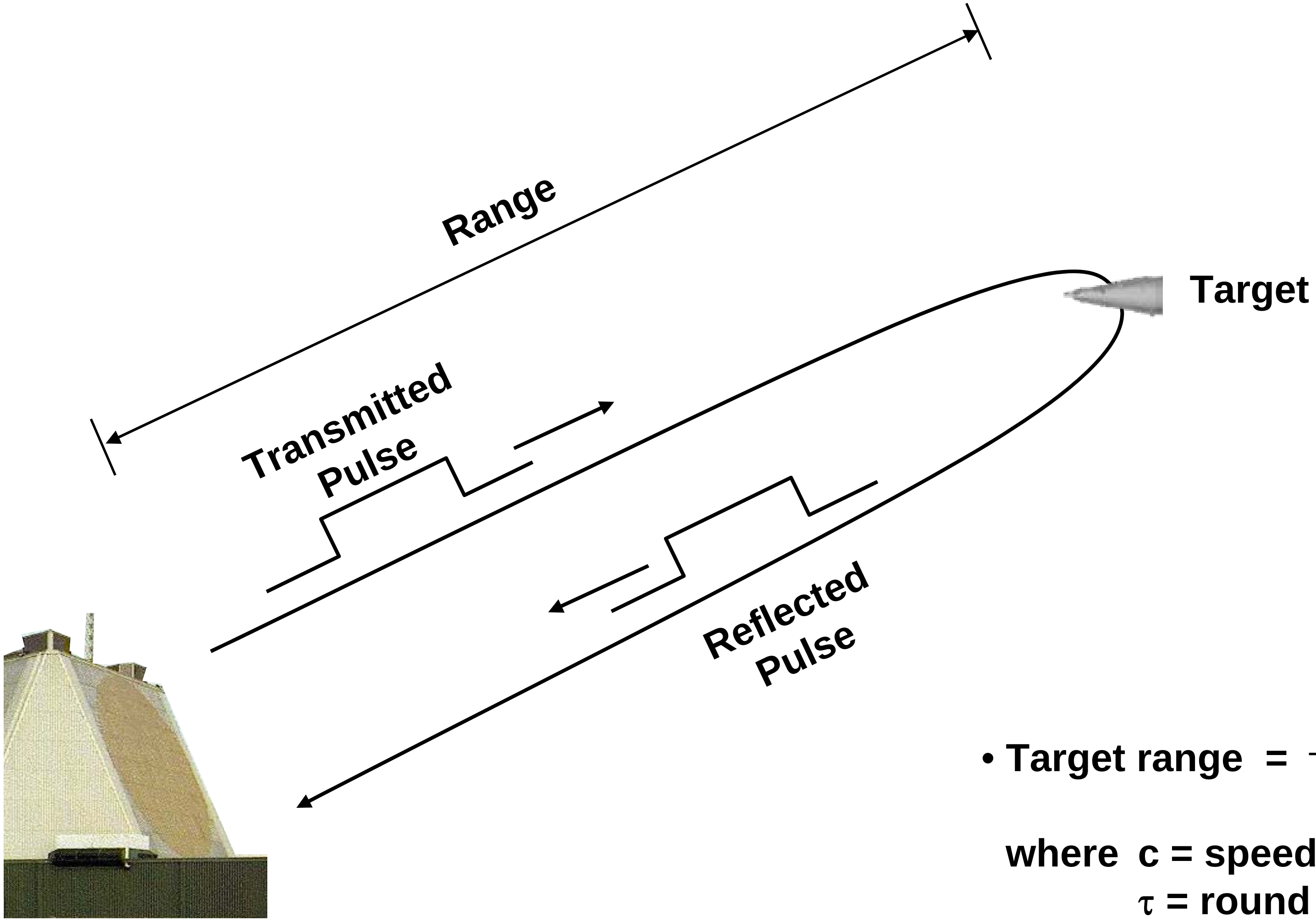
Pulse with changing frequency





Linear Frequency-Modulated (LFM) Waveform

Radar Range Measurement



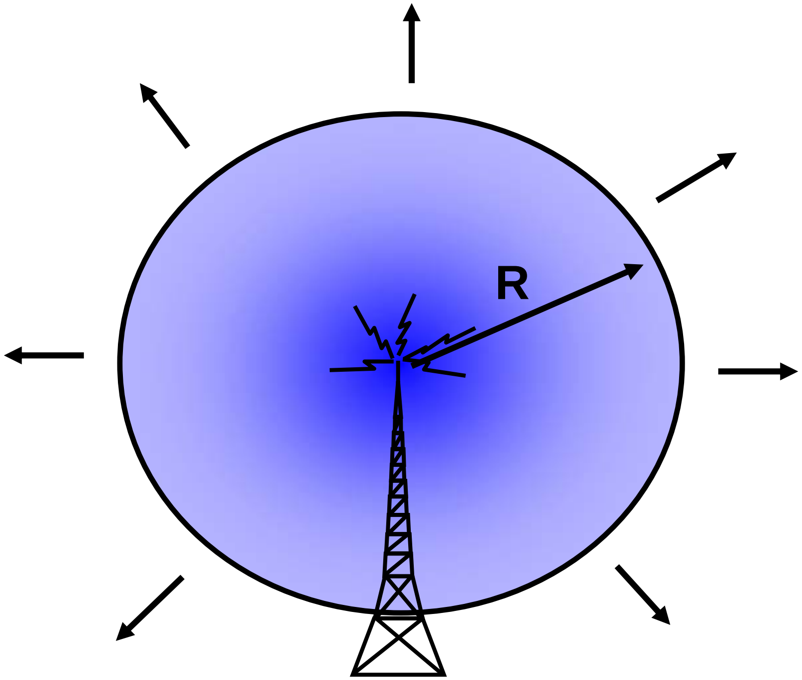
- Target range $= \dfrac{c\tau}{2}$

where c = speed of light
τ = round trip time

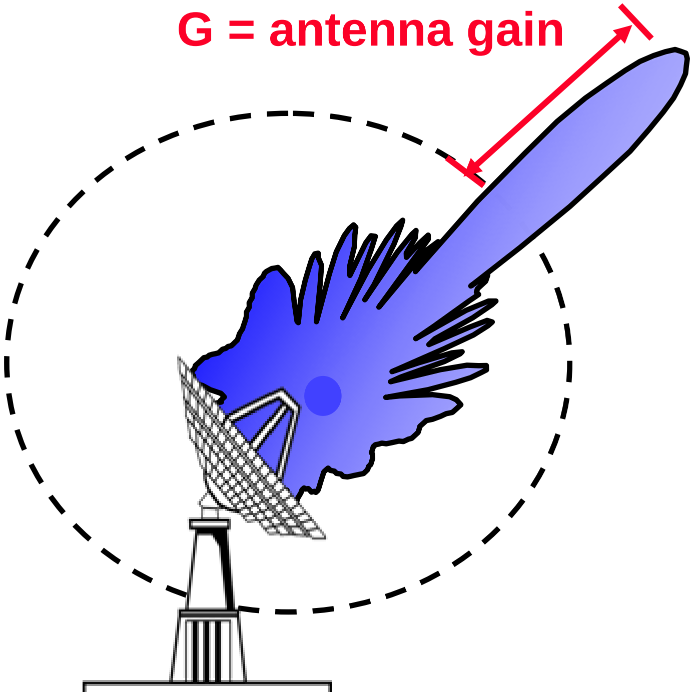
Courtesy of Raytheon. Used with permission.

Antenna Gain

Isotropic antenna

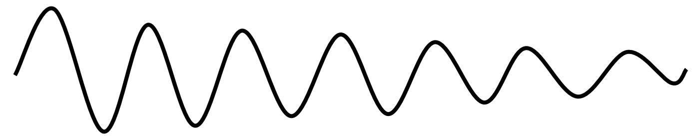


Directional antenna

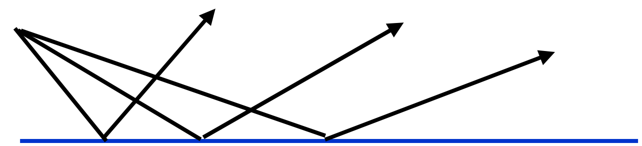


Propagation Effects on Radar Performance

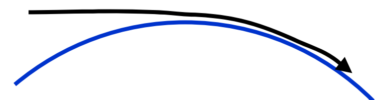
- **Atmospheric attenuation**



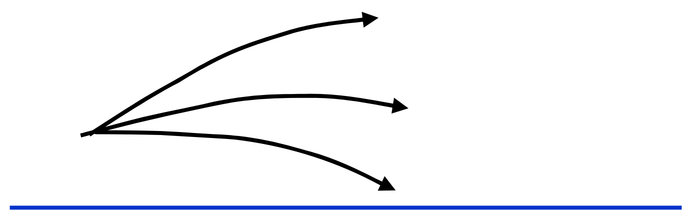
- **Reflection off of earth's surface**



- **Over-the-horizon diffraction**

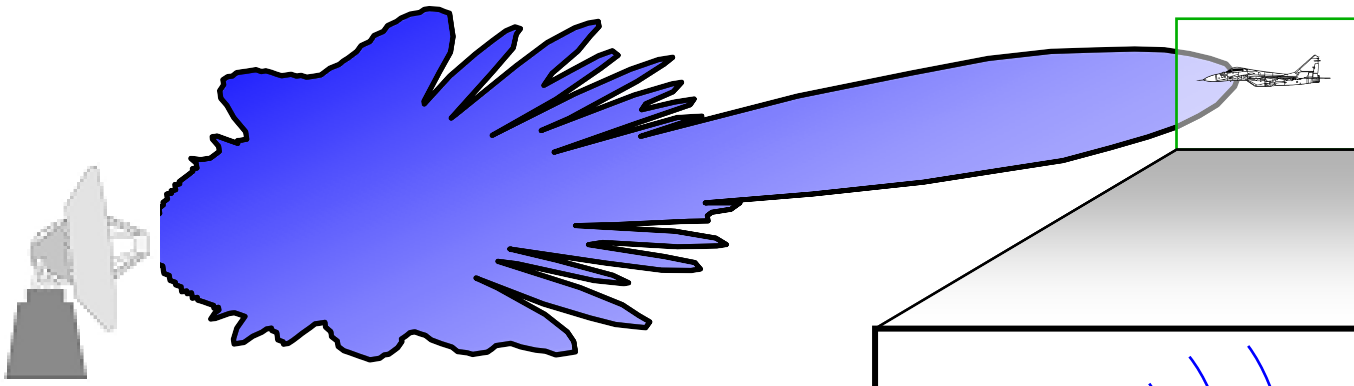


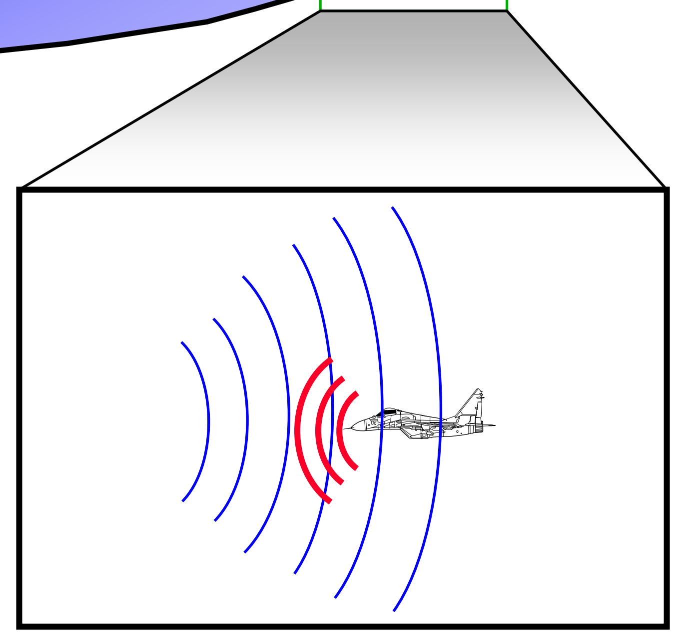
- **Atmospheric refraction**



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

Radar Cross Section (RCS)





Incident Power Density (Watts/m^2)	x	**RCS** 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

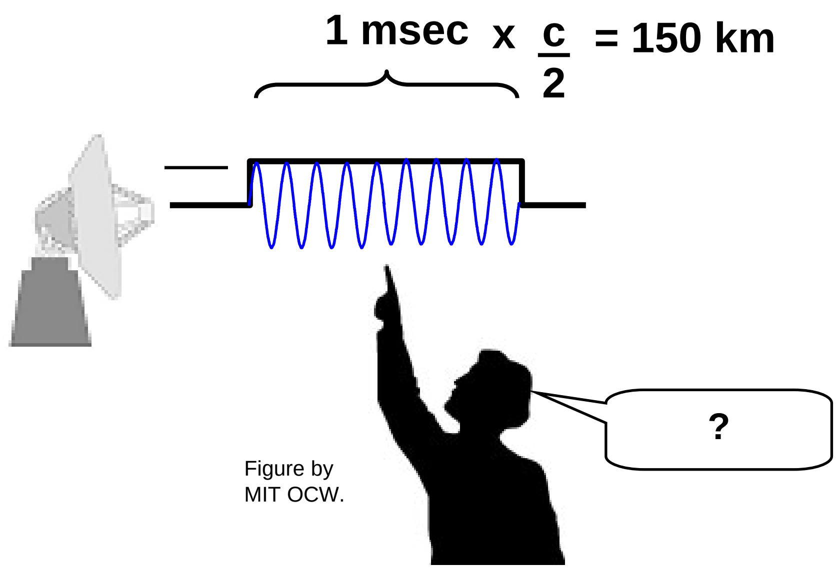
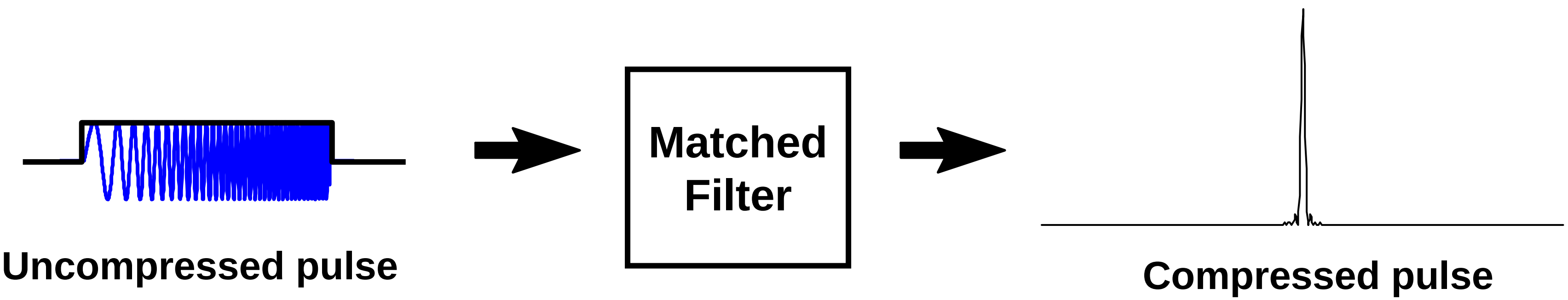
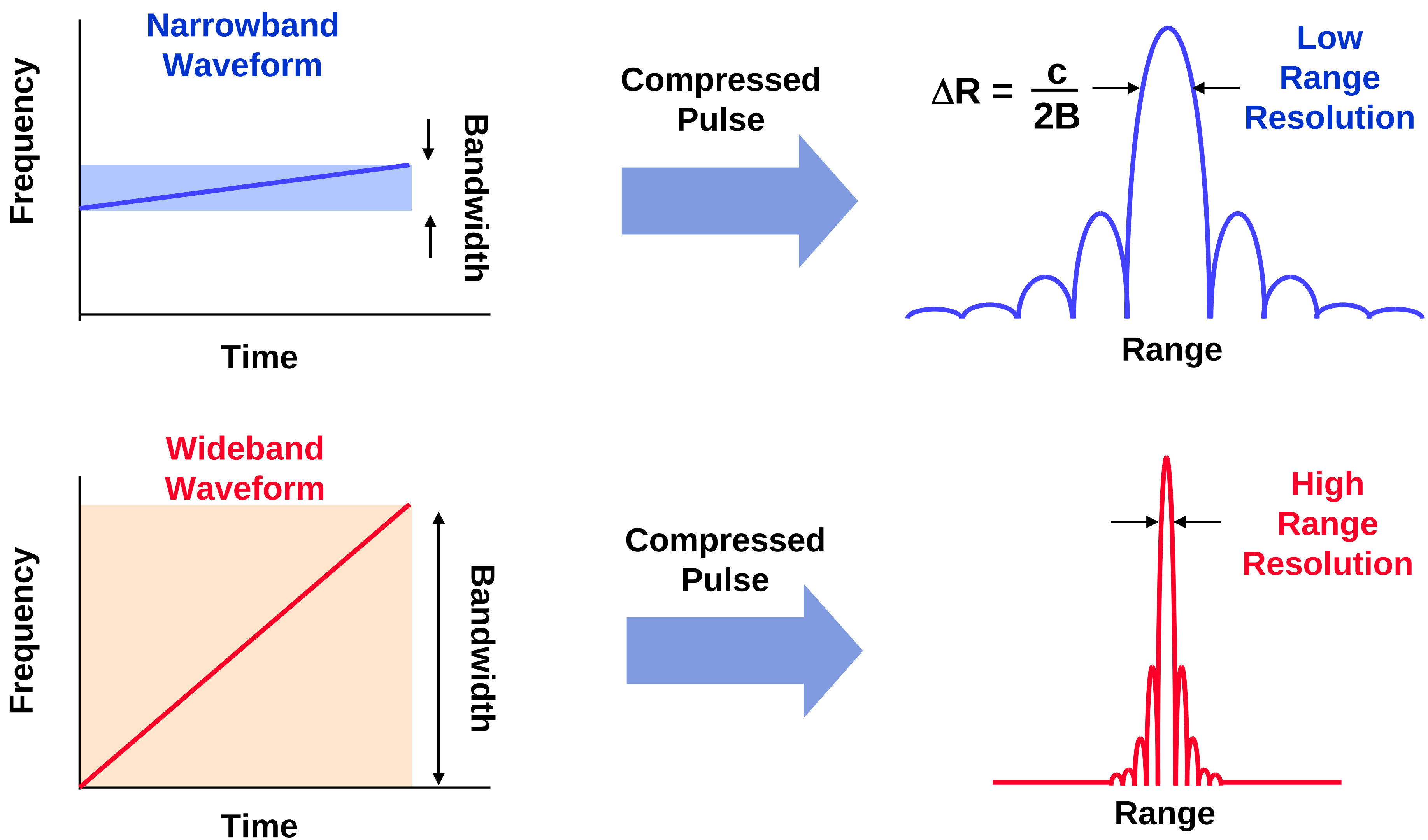


Figure by MIT OCW.

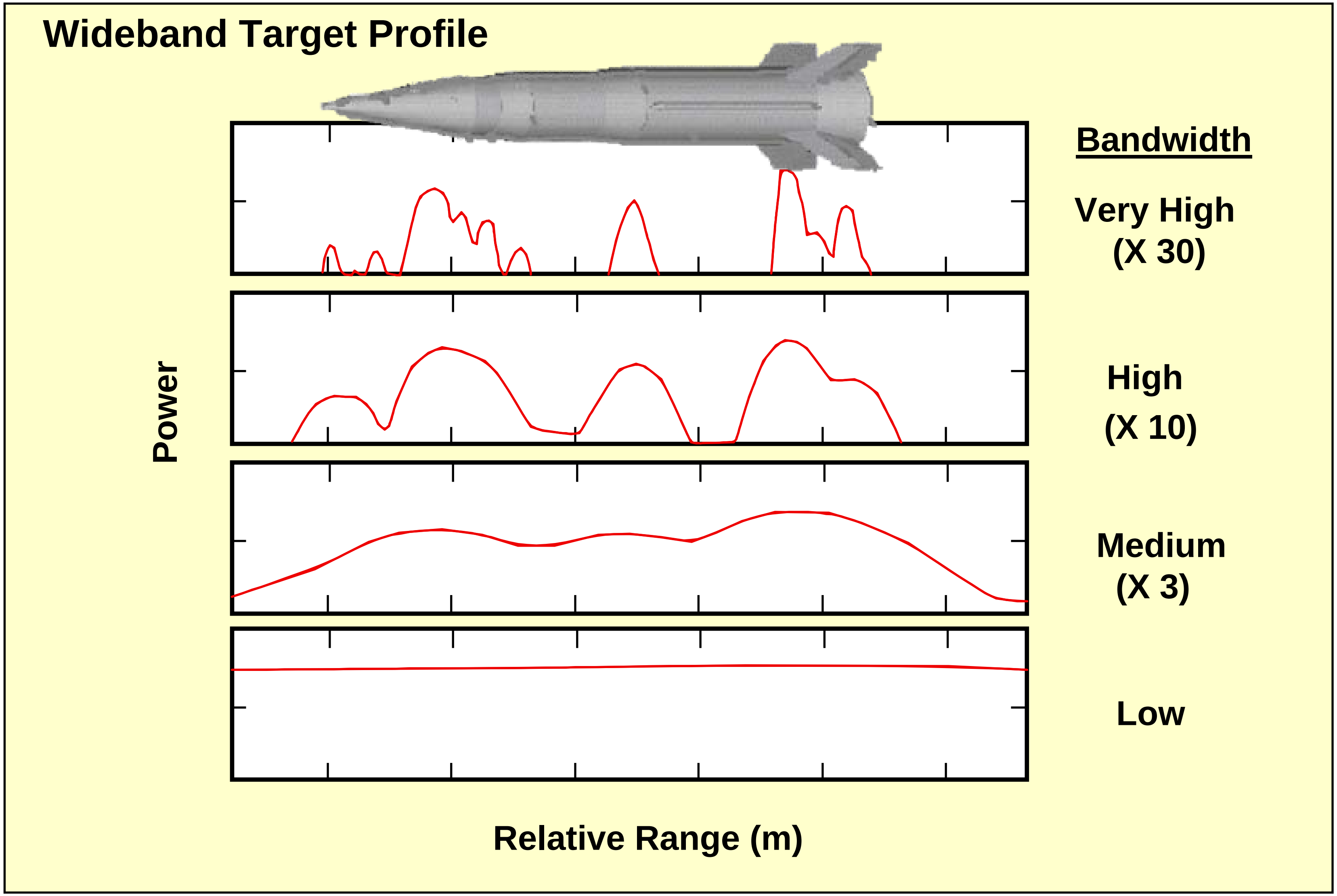
Solution: Use pulse with changing frequency and signal process using “matched filter”



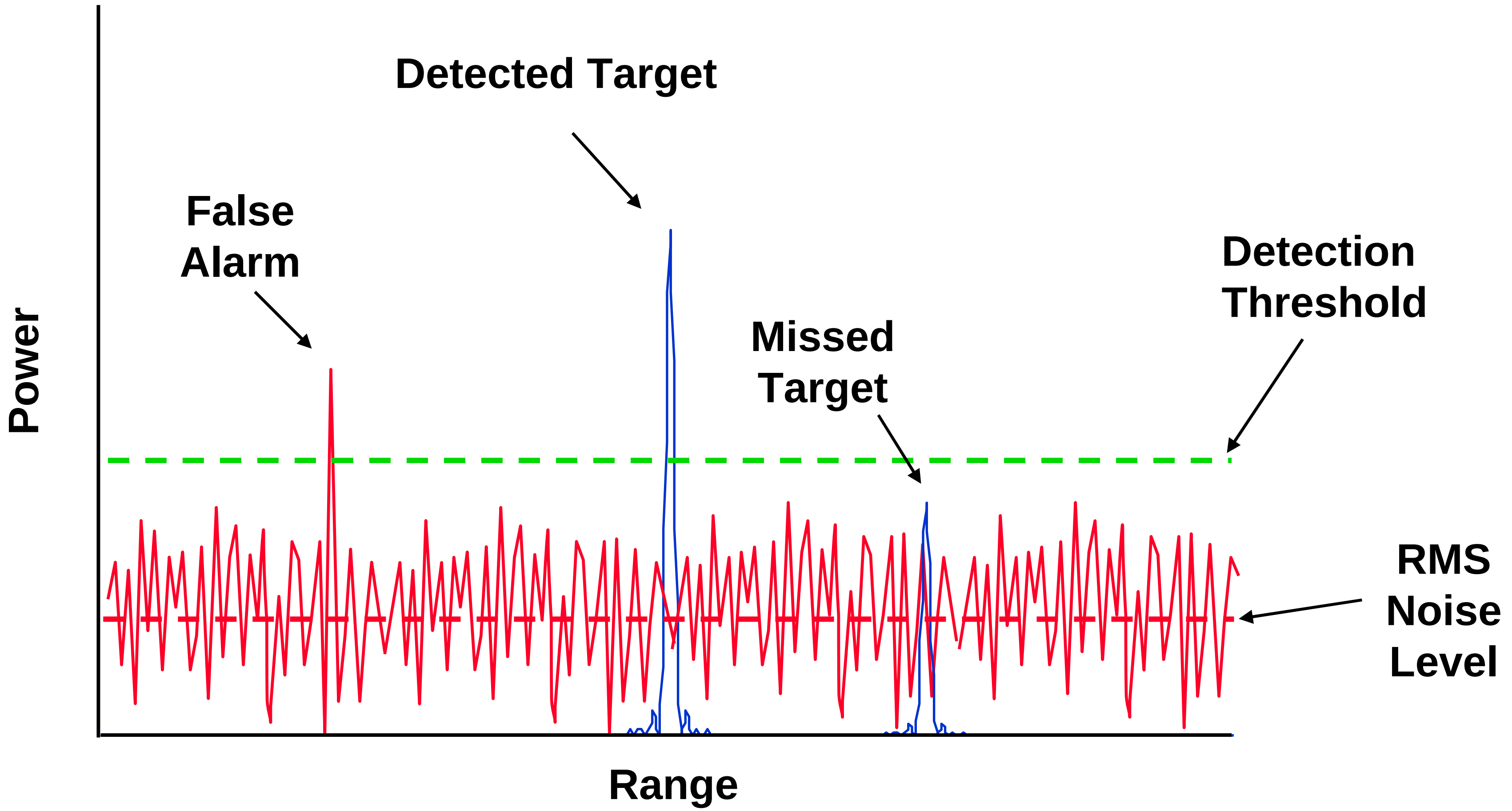
Bandwidth


Narrowband Waveform
Frequency
Time
Bandwidth
Compressed Pulse
$\Delta R = \frac{c}{2B}$
Low Range Resolution
Range
Wideband Waveform
Frequency
Time
Bandwidth
Compressed Pulse
High Range Resolution
Range

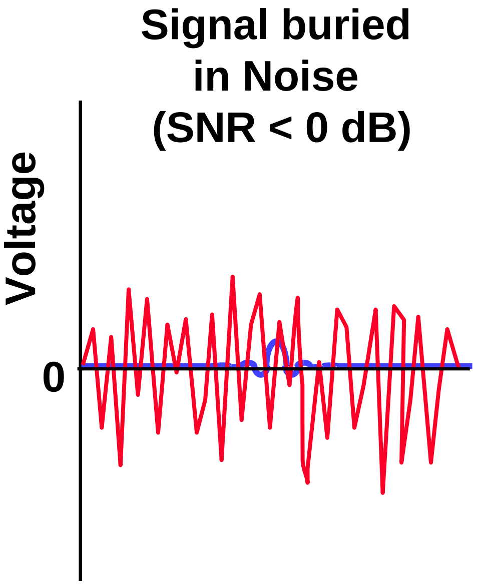
Why Bandwidth is Important

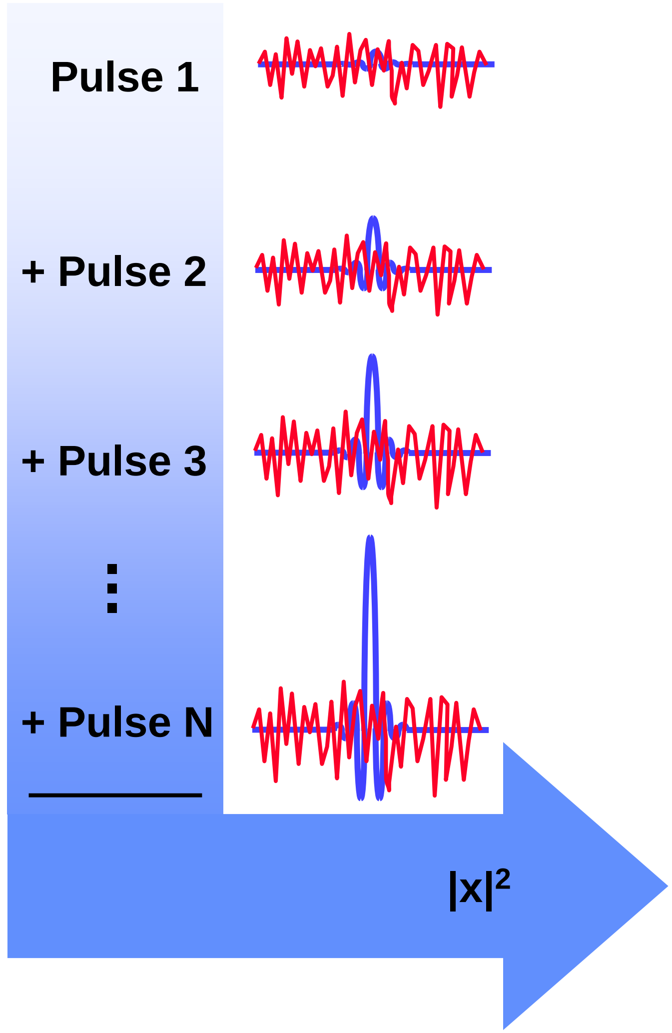


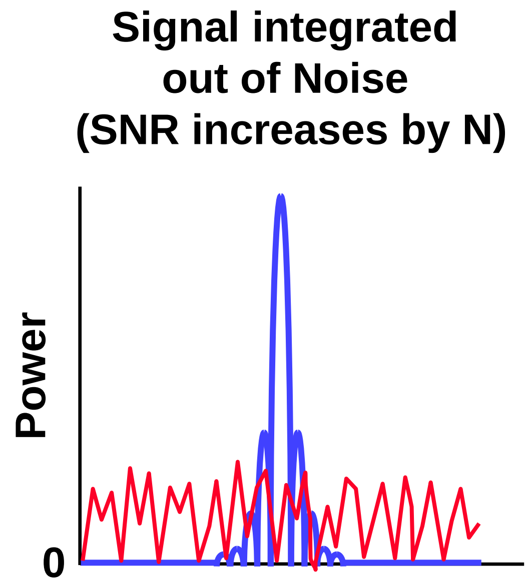
Detection of Signals in Noise



Coherent Integration







- Signals are same each time; add “coherently” (N^2)
- Noise is different each time; doesn’t add coherently (N)

Doppler Effect

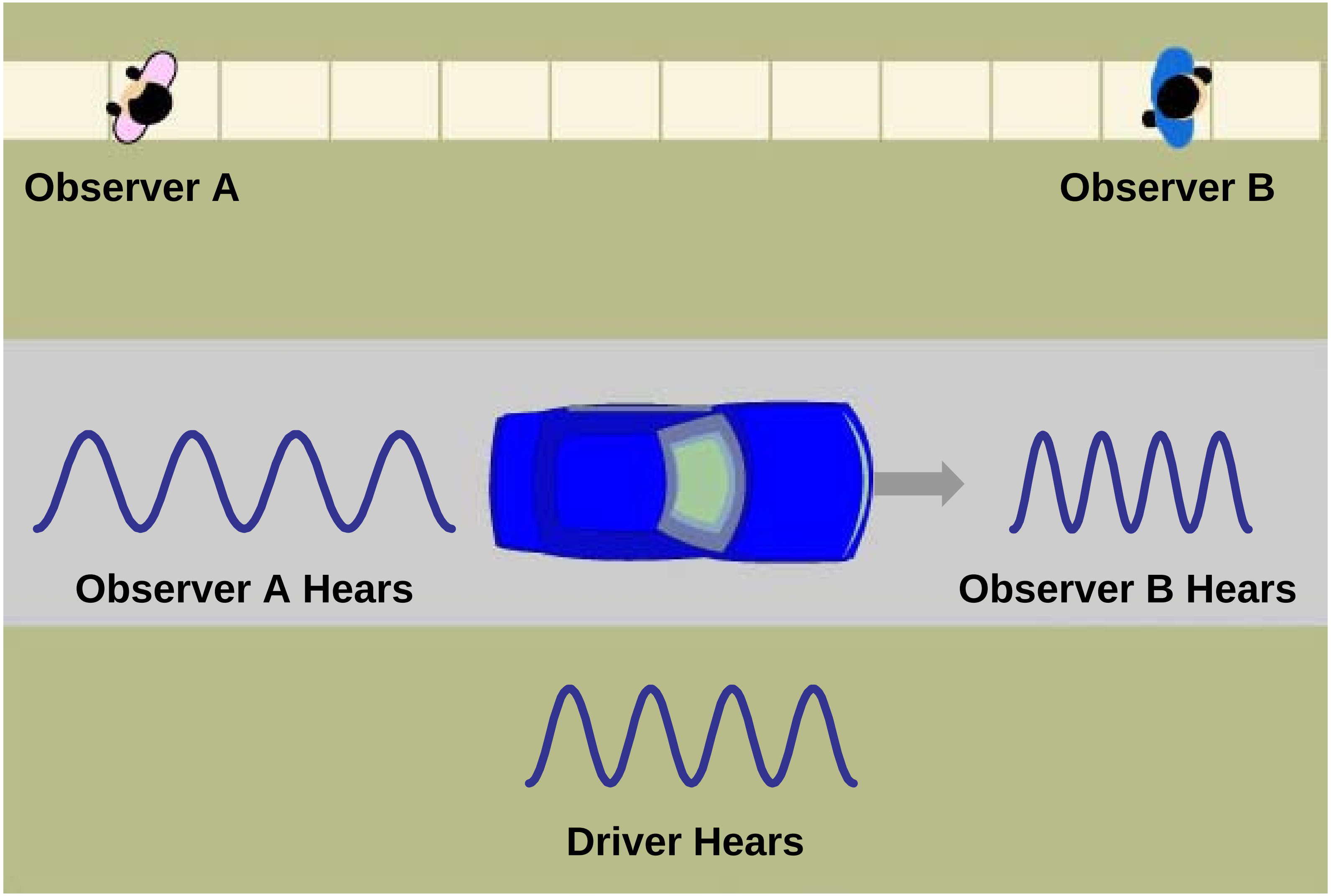
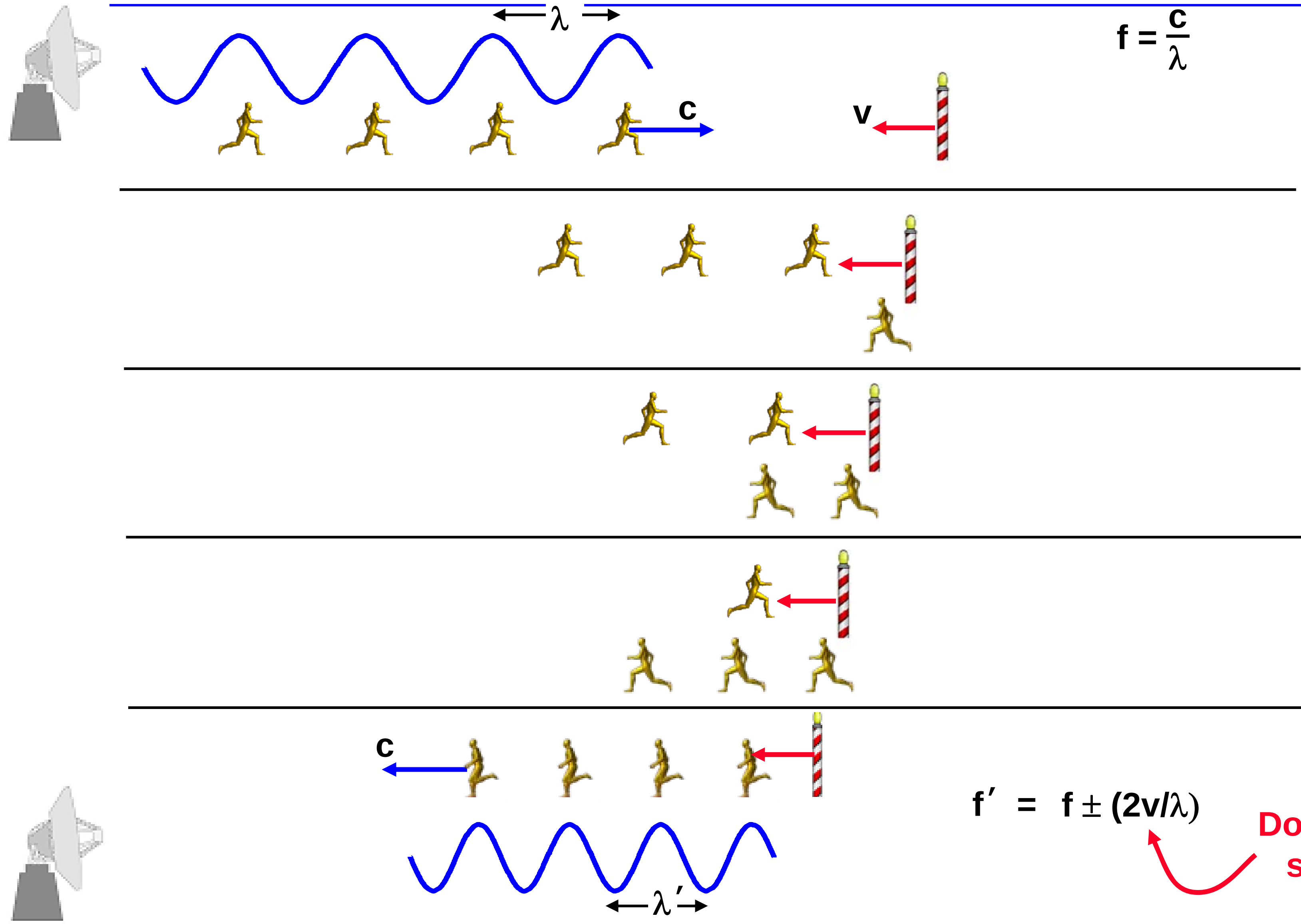


Figure by MIT OCW.

Doppler Shift Concept



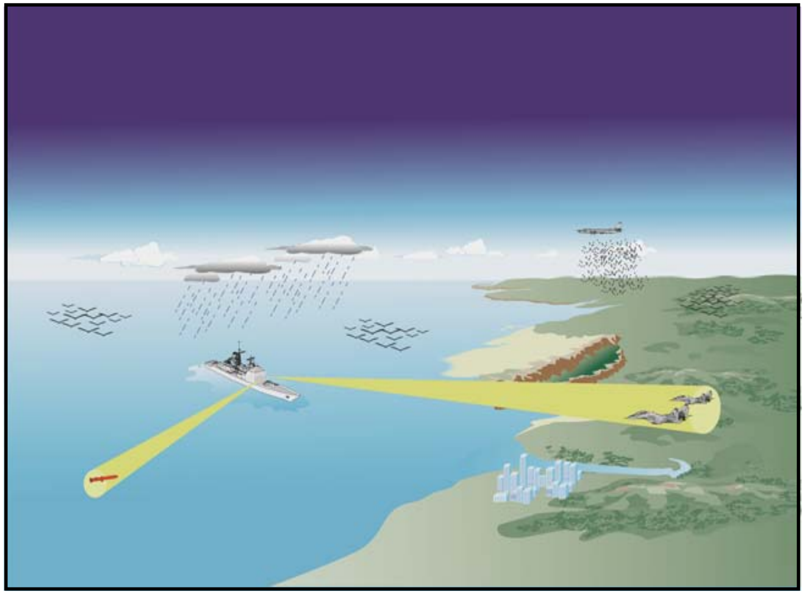
$$f = \frac{c}{\lambda}$$

$$f' = f \pm (2v/\lambda)$$

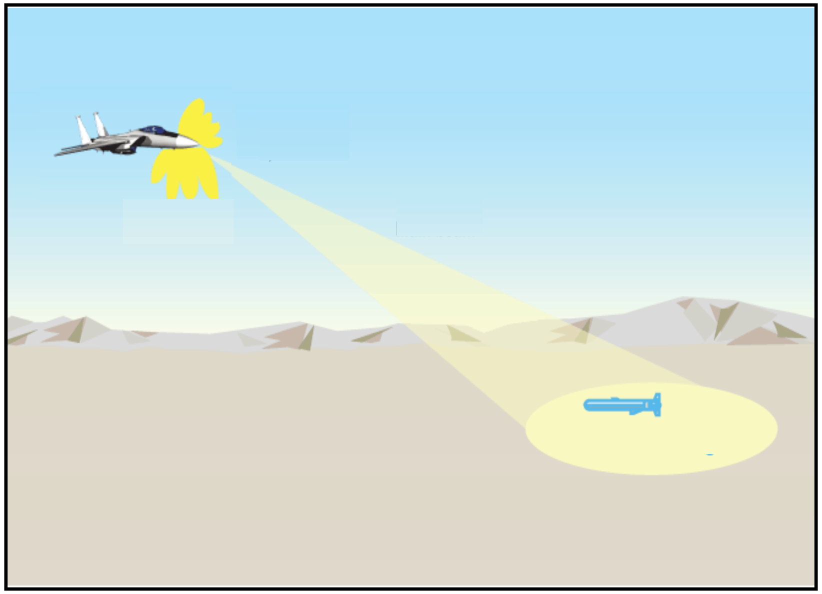
Doppler shift

Why Doppler is Important

Surface Radar



Airborne Radar



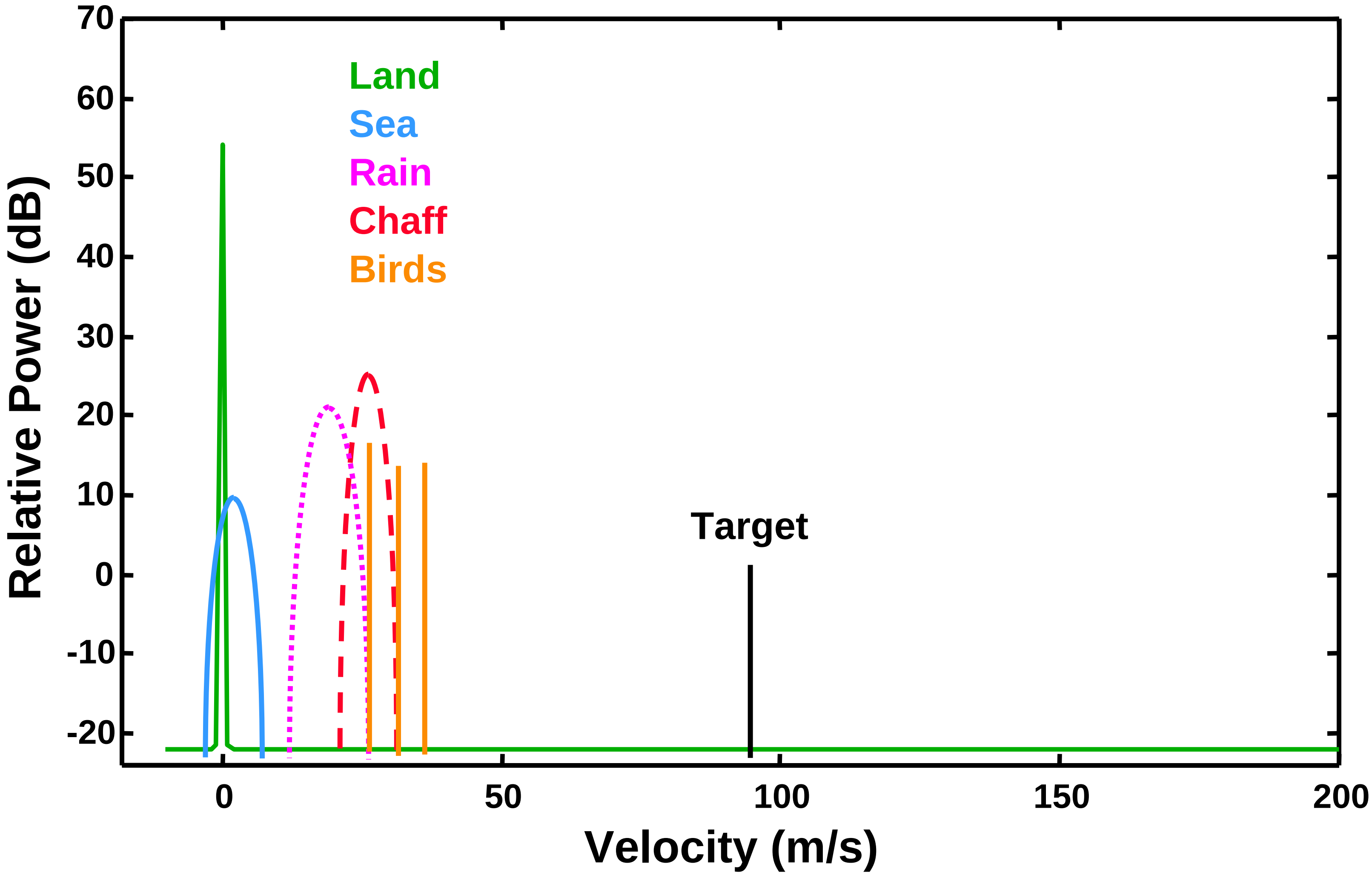
Clutter returns are much larger than target returns…

…however, targets move, clutter doesn't.

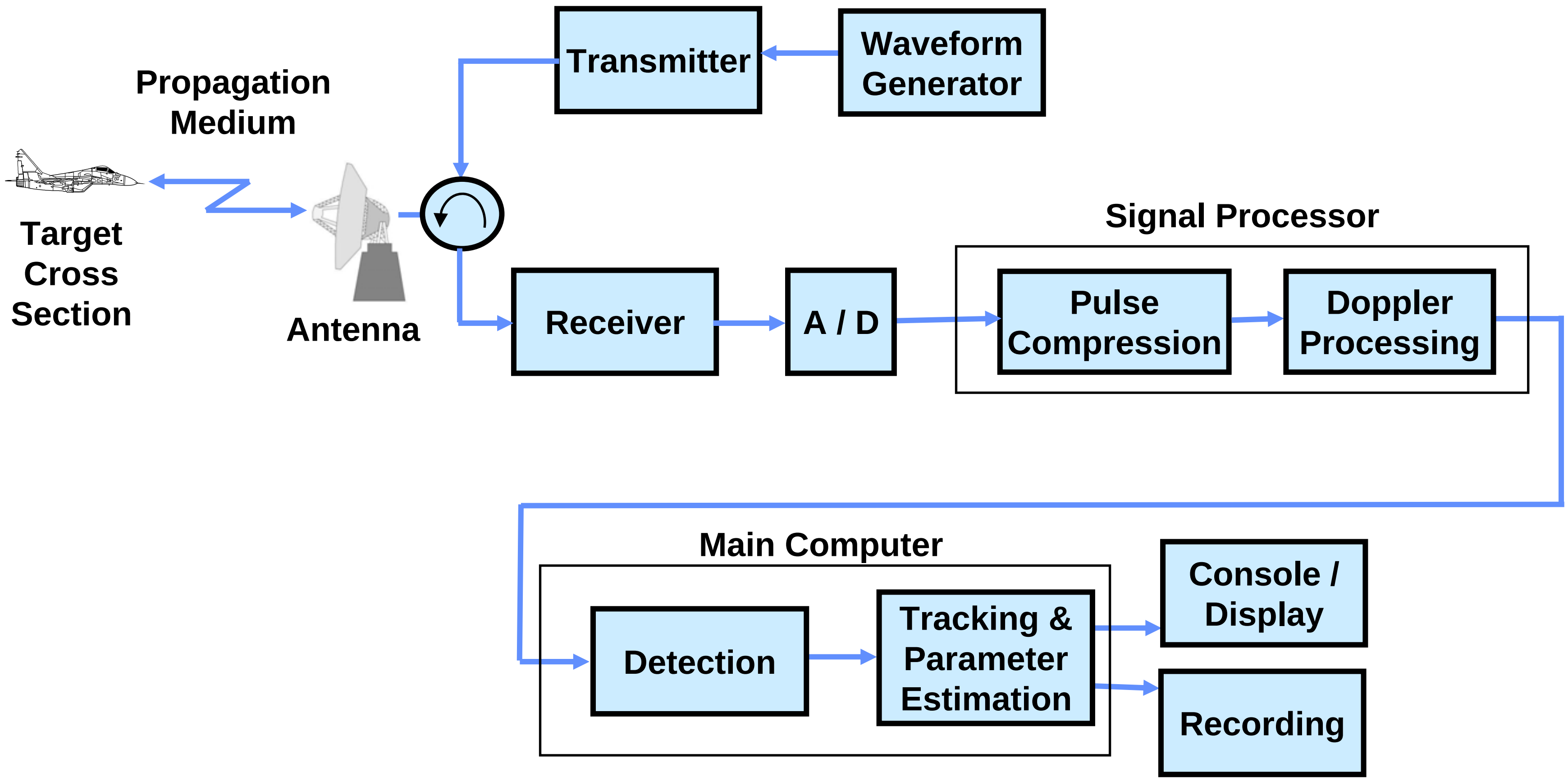
Note: if you're moving too, you need to take that into account.

Doppler lets you separate things that are moving from things that aren't

Clutter Doppler Spectra



Radar Block Diagram



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