Radar Basics

- Electromagnetic spectrum
- Radio Waves and Propagation
- Antennas
- Radar fundamentals
  - Radar targets and cross-sections
  - Radar equation
  - Doppler
- Volume scattering

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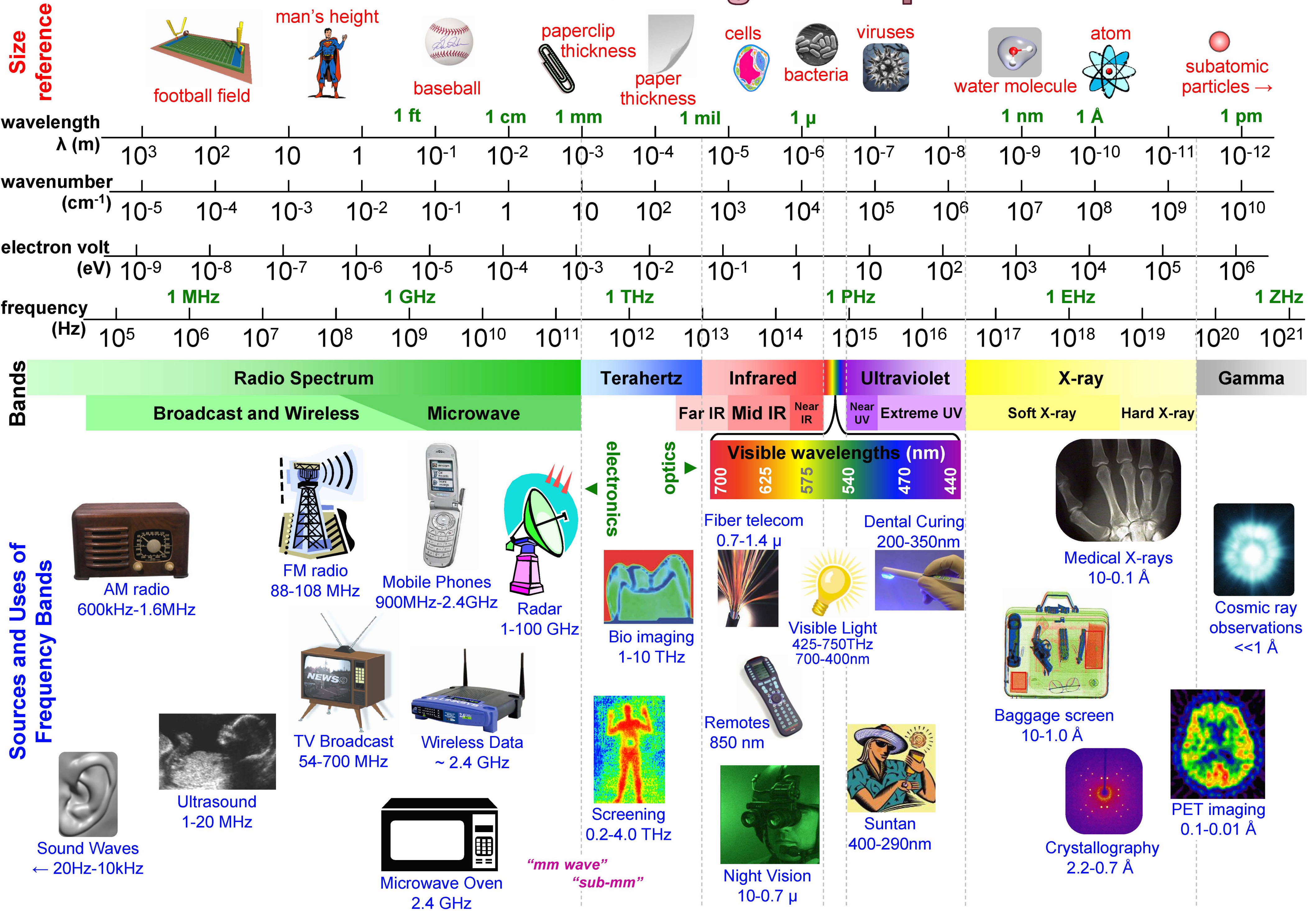
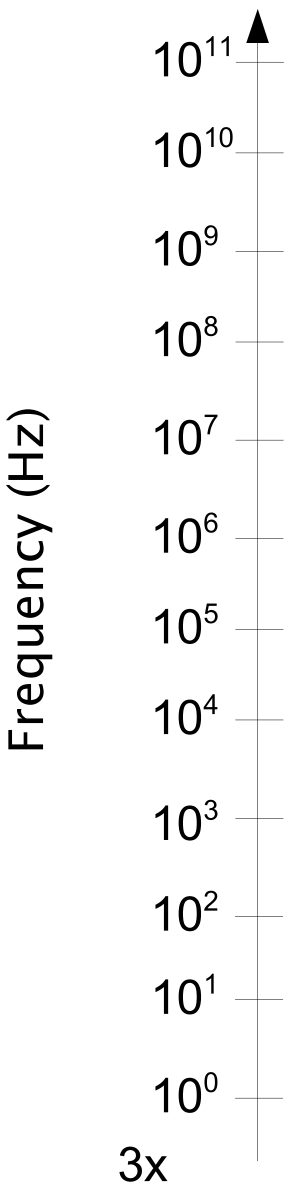
AMISR Summer School 2010

Chart of the Electromagnetic Spectrum



$\lambda = 3x10^8/freq = 1/(wn*100) = 1.24x10^{-6}/eV$

Radio Spectrum



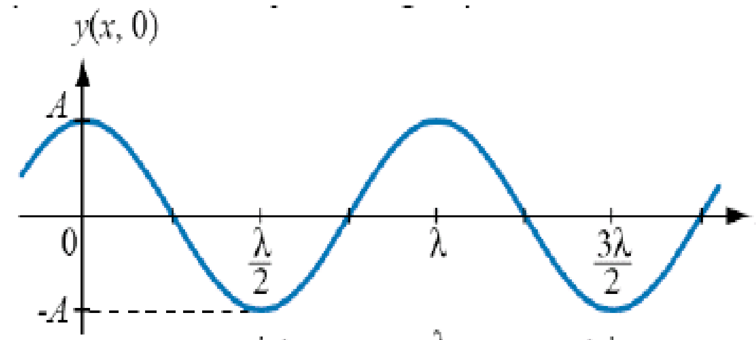
Band	Applications
Extremely High Frequency EHF (30 - 300 GHz)	Radar, advanced communication systems, remote sensing, radio astronomy
Super High Frequency SHF (3 - 30 GHz)	Radar, satellite communication systems, aircraft navigation, radio astronomy, remote sensing
Ultra High Frequency UHF (300 MHz - 3 GHz)	TV broadcasting, radar, radio astronomy, microwave ovens, cellular telephone
Very High Frequency VHF (30 - 300 MHz)	TV and FM broadcasting, mobile radio communication, air traffic control
High Frequency HF (3 - 30 MHz)	Short wave broadcasting
Medium Frequency MF (300 kHz - 3 MHz)	AM broadcasting
Low Frequency LF (30 - 300 kHz)	Radio beacons, weather broadcast stations for air navigation
Very Low Frequency VLF (3 - 30 kHz)	Navigation and position location
Ultra Low Frequency ULF (300 Hz - 3 kHz)	Audio signals on telephone
Super Low Frequency SLF (30 - 300 Hz)	Ionospheric sensing, electric power distribution, submarine communication
Extremely Low Frequency ELF (3 - 30 Hz)	Detection of buried metal objects
$f < 3$ Hz	Magnetotelluric sensing of the earth's structure

Radio Waves

$y(x, t) = A\cos(\omega t - kx + \phi_o)$

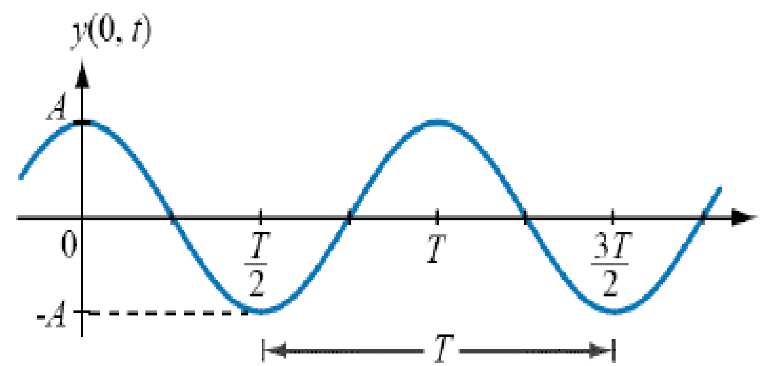
Angular Frequency
$\omega = 2\pi f = 2\pi/T$

Wavenumber
$k = 2\pi/\lambda$



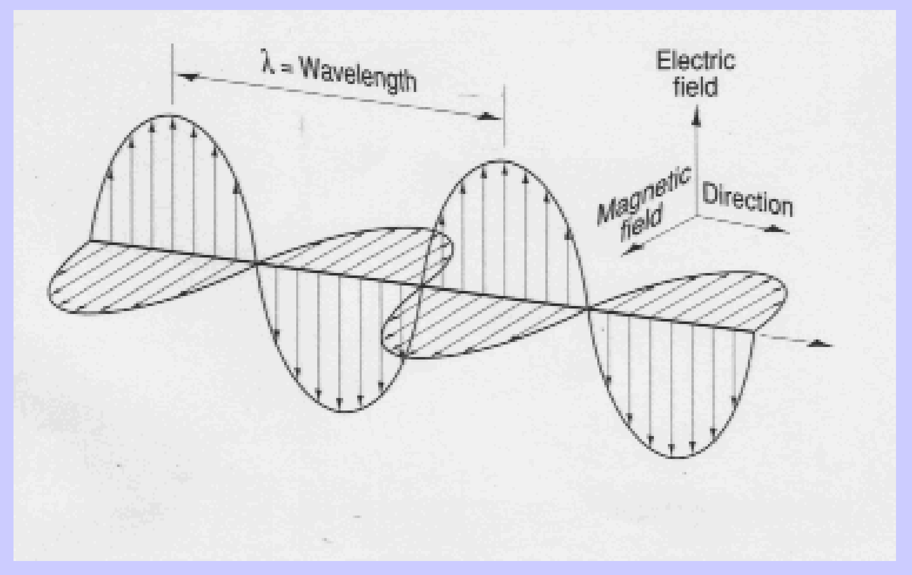
(a) $y(x, t)$ versus x at $t = 0$

Wave phase velocity
$c = f\lambda = \omega/k = 3x10^8\ m/s$



(b) $y(x, t)$ versus t at $x = 0$

TEM Waves



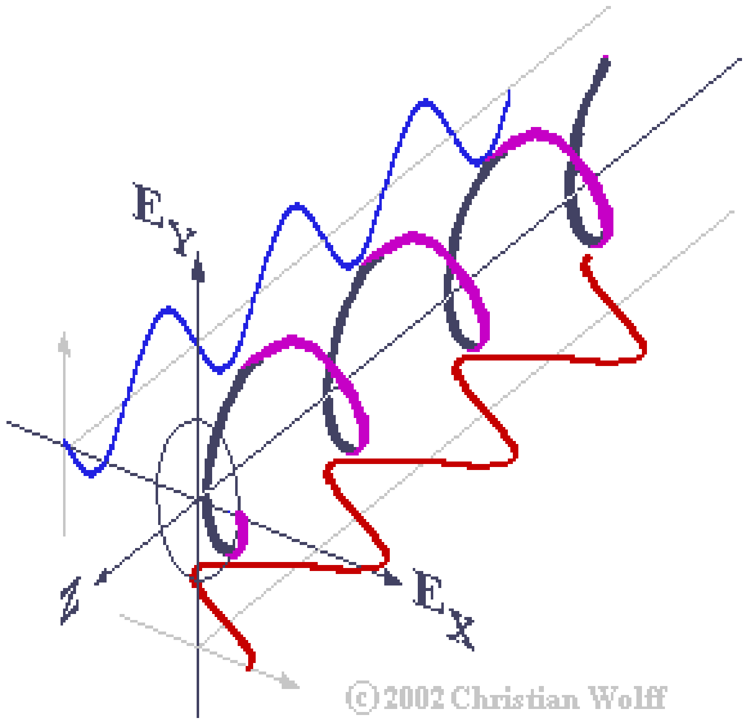
Electromagnetic waves propagate

Polarization $\overline{\mathrm{E}} = (\mathrm{E}_1 \hat{x} + \mathrm{E}_2 \hat{y} e^{j\varphi})\, e^{j(\omega t - kx)}$

$\alpha = \tan^{-1} \mathrm{E}_y/\mathrm{E}_x$

Linear: $\psi = 0$, $\alpha = \mathrm{E}_2/\mathrm{E}_1$

Circular: $\psi = \pi/2$, $\alpha = \mp(\omega t - kx)$



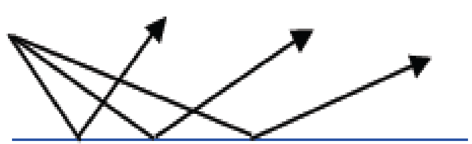
Propagation Medium

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

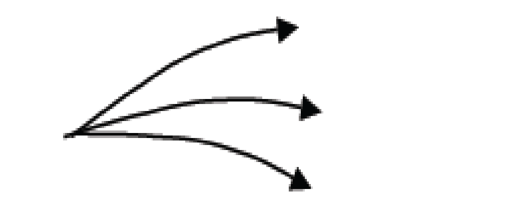
- **Atmospheric attenuation**

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



- **Over-the-horizon diffraction**

- **Atmospheric refraction**



Attenuation usually measured in dB

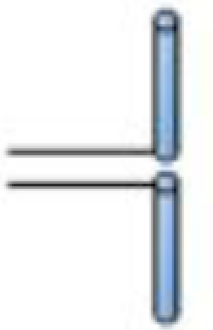
Example:

$$SNR(dB) = 10 \log_{10} \left\{ \frac{\text{Signal Power}}{\text{Noise Power}} \right\}$$

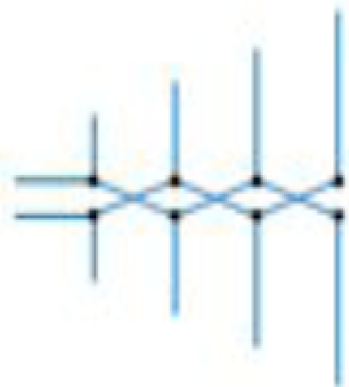
0 dB = Factor of 1
3 dB = Factor of 2
10 dB = Factor of 10
100 dB = Factor of 20

Antennas

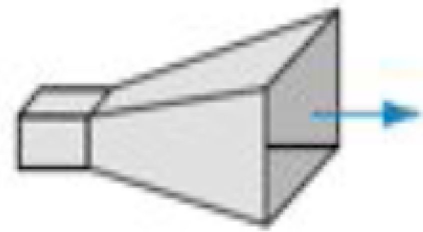
Most basic form of antennas – a wire element with a time varying current flowing in it



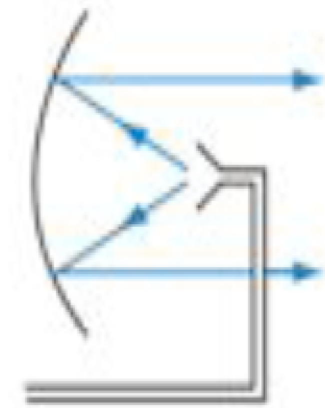
Dipole antenna



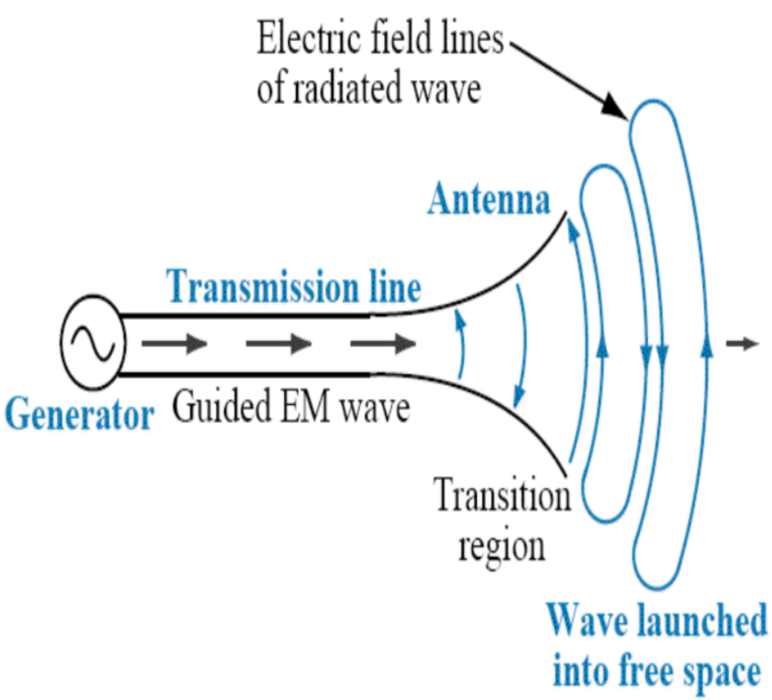
Log Periodic

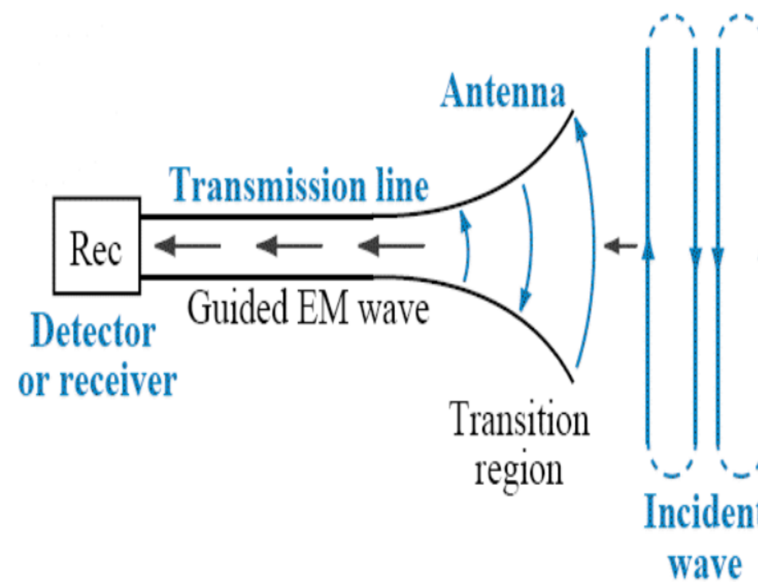


Horn antenna



Parabolic dish Reflector antenna





Gain and Effective Area

$$\text{Gain} = \frac{\text{Maximum Power Density}}{\text{Power delivered to Anteanna } / 4\pi R^2}$$

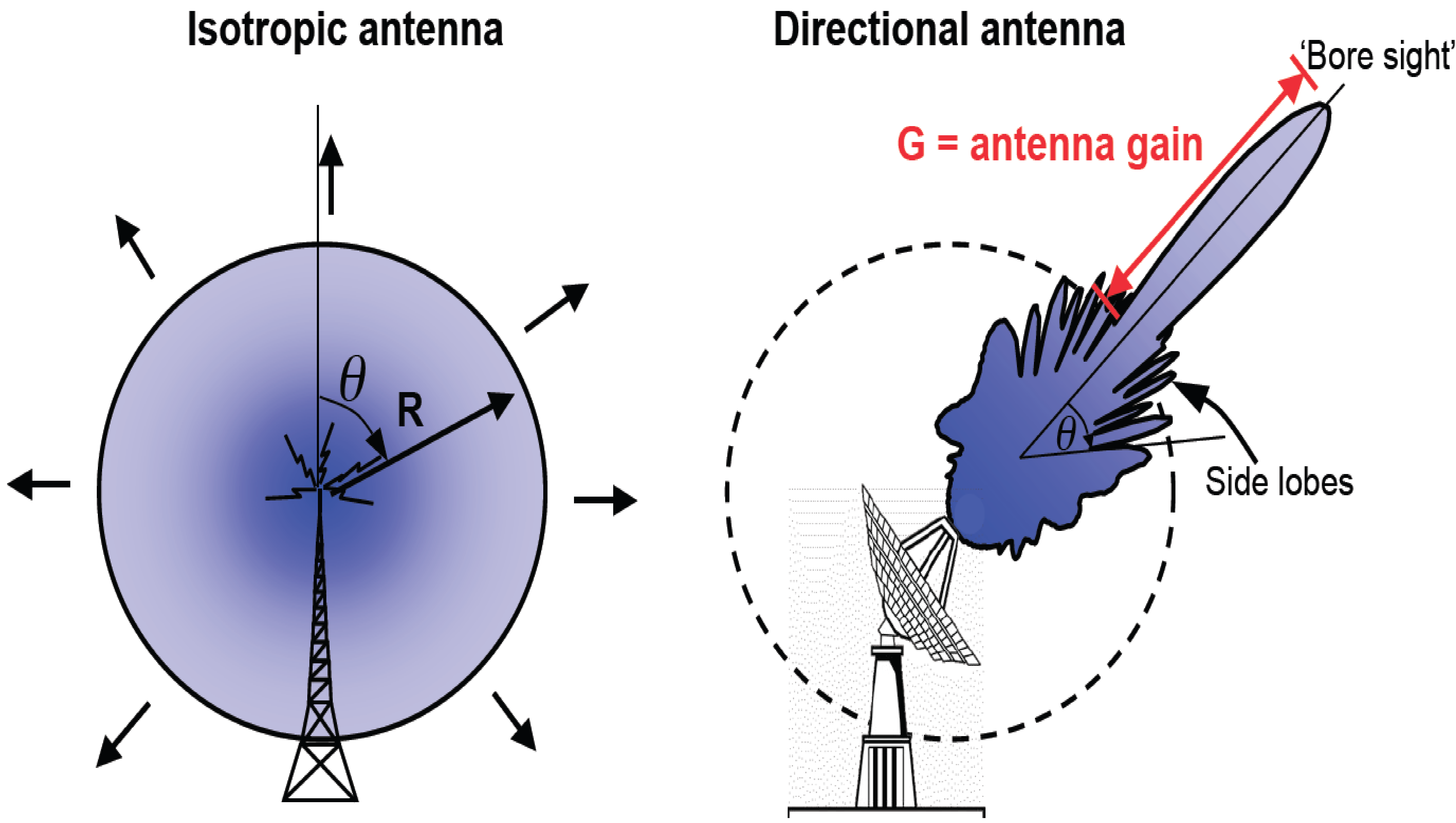
$$\boxed{G = \frac{4\pi}{\lambda^2} A_{eff}}$$

$$A_{eff} \leq A_{phys}$$

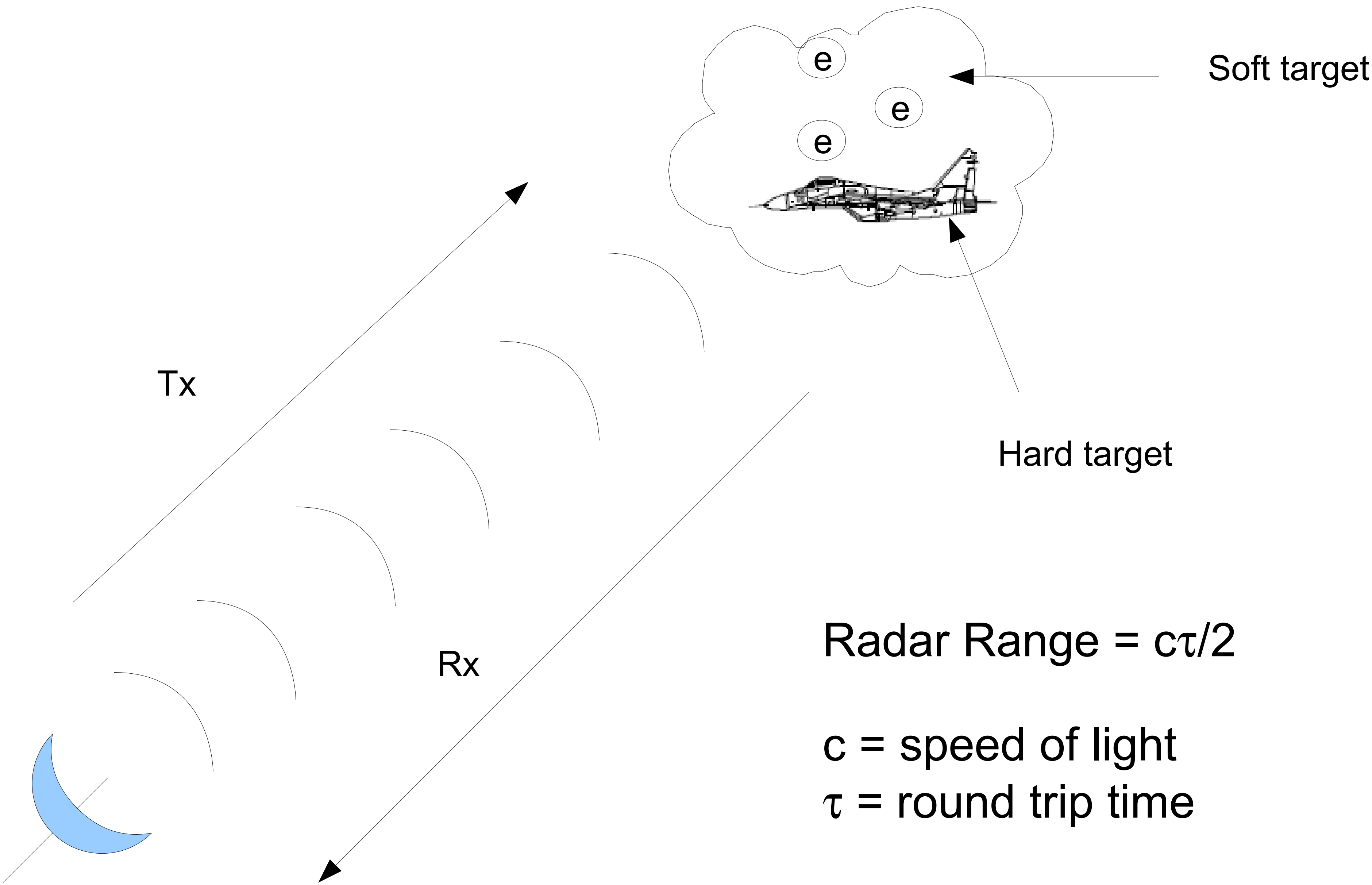
$$P_r\,[w] = P_{inc}\,[w/\mathrm{m}^2] \times A_{eff}\,[\mathrm{m}^2]$$

For aperture antennas, Aeff/Aphys ~ 0.5 to 0.7

Radiation Pattern



RAdio Detection And Ranging



Radar Range = $c\tau/2$

c = speed of light
τ = round trip time

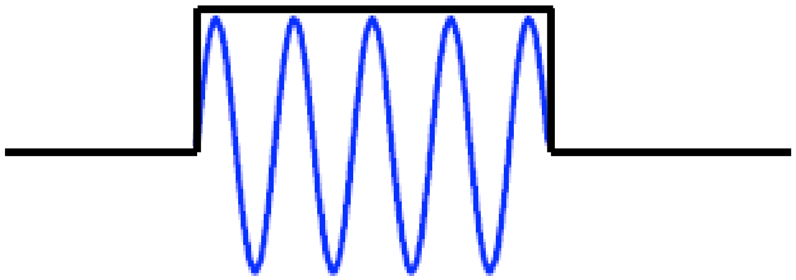
Radar equation

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

Radar cross section tells us about the target properties

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

What the radar transmits: Pulses and waves

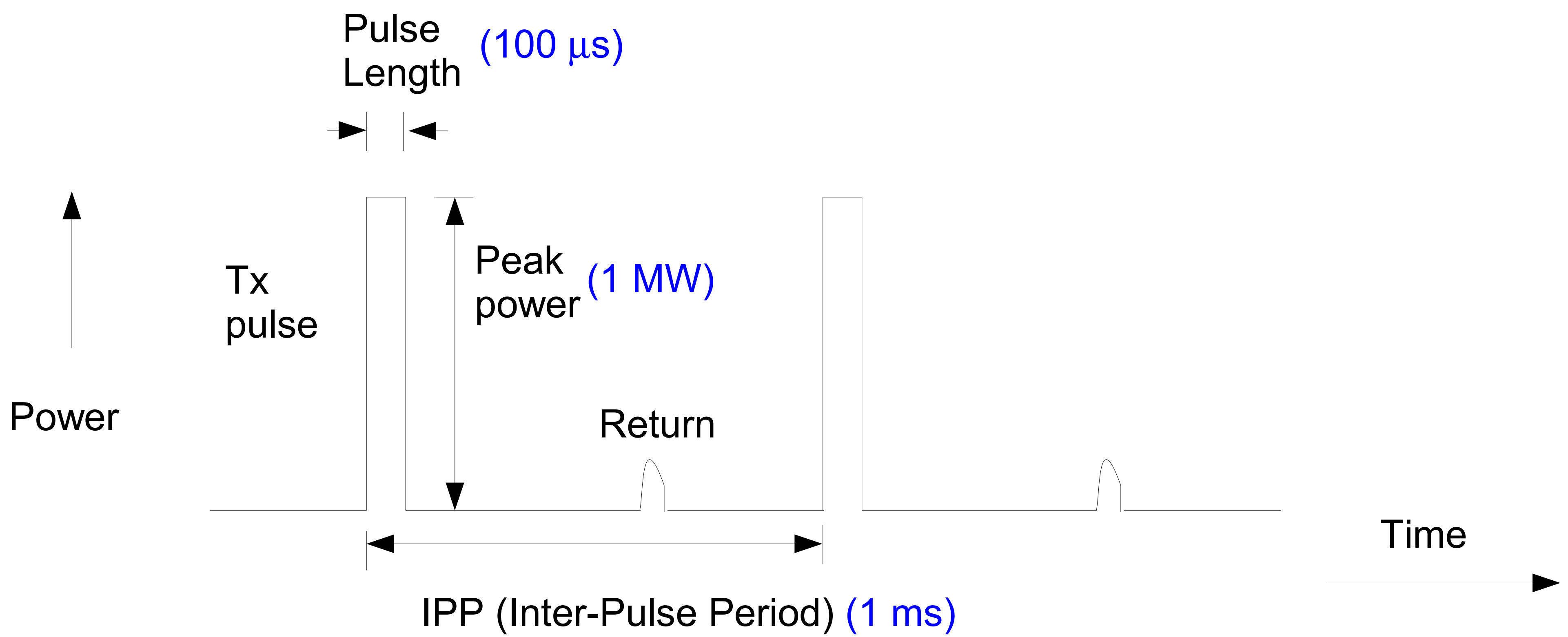


Cycles in a pulse.

PFISR frequency = 449 MHz
Long pulse length = 480 μs
# of cycles = 215520 !

Radar waveforms modulate the waves with on-off sequence

Pulsed Radar



Duty cycle = Pulse Length/IPP (10%)
Average power = Peak power x Duty cycle (100 kW)
PRF (Pulse Repetition Frequency) = 1/IPP (1kHz)

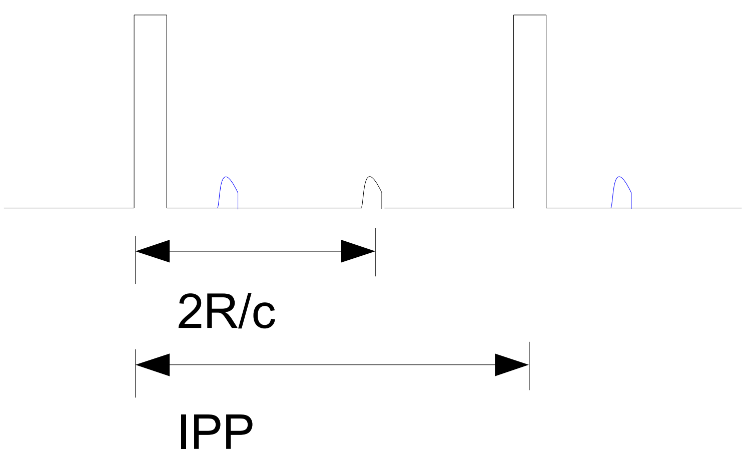
Duty cycle for a CW (continuous wave) radar 100%

Range Resolution

Range resolution is set by pulse length

Pulse length = τ_p , Range resolution = $c\tau_p/2$ for a single target.

Maximum unambiguous range

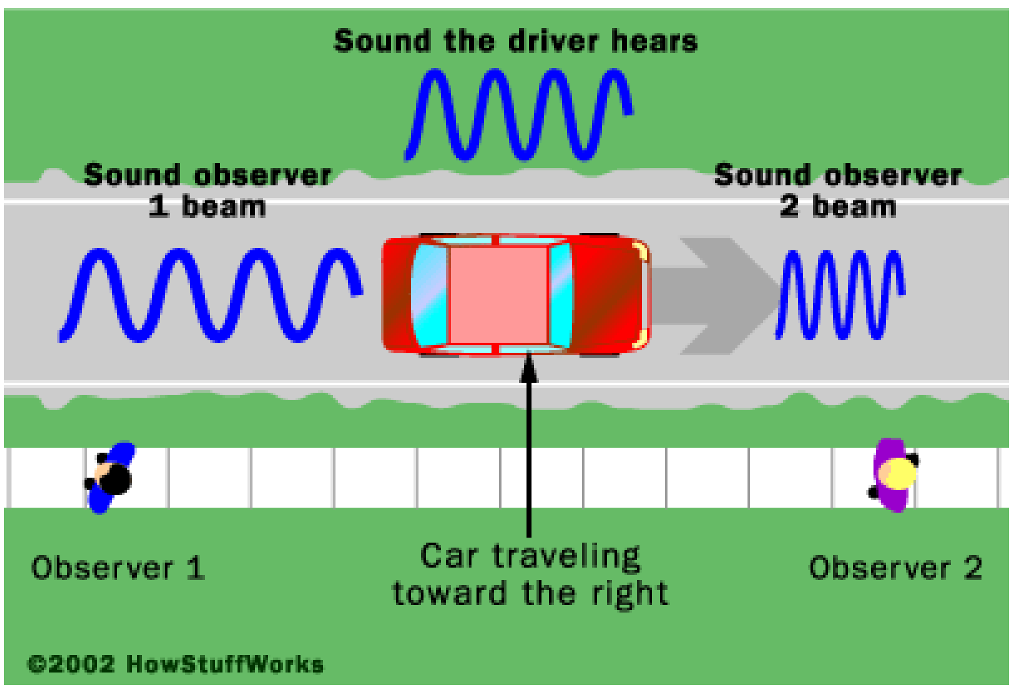


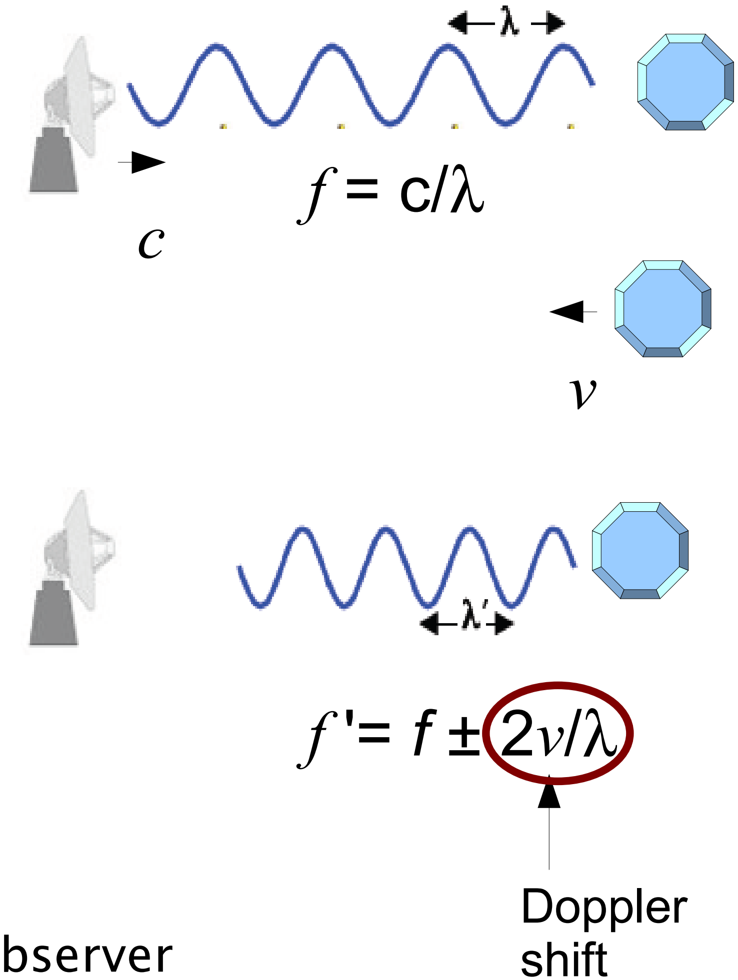
MUR = c*IPP/2

Pulse duration vs. Range resolution

Pulse Duration	Range Resolution
0.1 nsec	1.5 cm
1.0 nsec	15 cm
10 nsec	1.5 m
100 nsec	15 m
1 μsec	150 m
10 μsec	1.5 km
100 μsec	15 km
1 msec	150 km

Moving target - Doppler





Positive Doppler = target moving **toward** the observer
Negative Doppler = target moving **away** from the observer

Doppler shift frequency

Tx signal: $\cos(2\pi f_o t)$

Return from a moving target: $\cos[2\pi f_o(t + 2R/c)]$

If target is moving with a constant velocity: $R = R_o + v_o t$

then,

Return: $\cos[2\pi(f_o + f_o 2v_o/c)t + 2\pi f_o R_o/c]$

Doppler frequency:
$-2f_o v_o/c = -2v_o/\lambda_o$

Resolving Doppler

Tx signal: $\cos(2\pi f_o t)$
Doppler shifted: $\cos[2\pi(f_o + f_D)t]$

Multiply by $\cos(2\pi f_o t)$ -> Low pass filter -> $\cos(2\pi f_D t)$

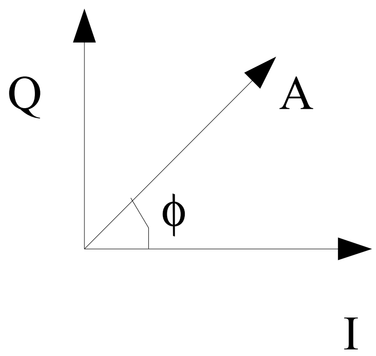
BUT, the sign of f_D is lost (cosine is an even function)

So, instead use
$\exp(j2\pi f_D t) = \cos(2\pi f_D t) + j\sin(2\pi f_D t)$

Generate this signal by mixing cos and sin via two oscillators (same frequency, 90^o out of phase)

Components are called I (In phase) and Q (Quadrature): $A\exp(j2\pi f_D t) = I + jQ$

I/Q Demodulation

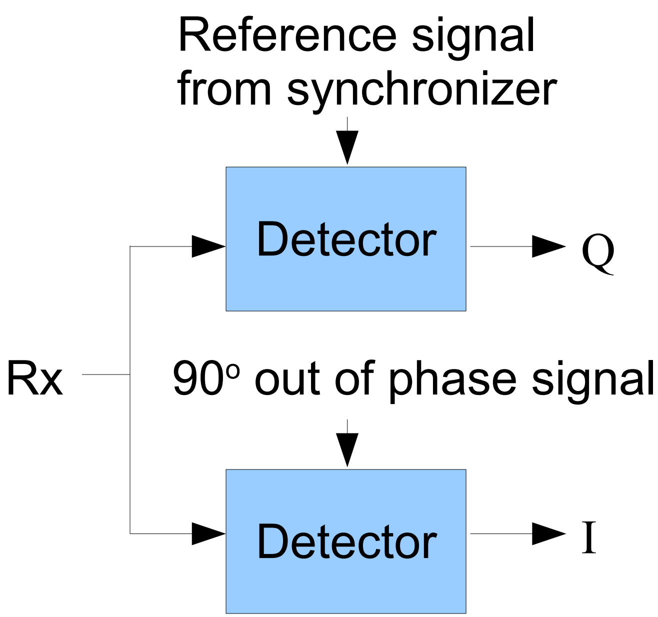


In phase (I):

$$\Pr(t)\cos(\omega_c t) = a(t)\cos(\phi(t) + \omega_c t)\cos(\omega_c t)$$
$$= a(t)\,(\tfrac{1}{2})\,(\cos(\phi(t) + 2\omega_c t) + \cos(\phi(t)))$$

Quadrature (Q): **filtered**

$$\Pr(t)\cos(\omega_c t) = a(t)\cos(\phi(t) + \omega_c t)\sin(\omega_c t)$$
$$= a(t)\,(\tfrac{1}{2})\,(-\sin(\phi(t) + 2\omega_c t) + \sin(\phi(t)))$$

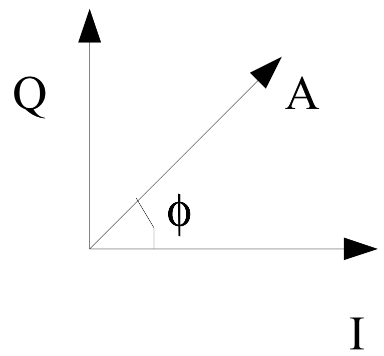


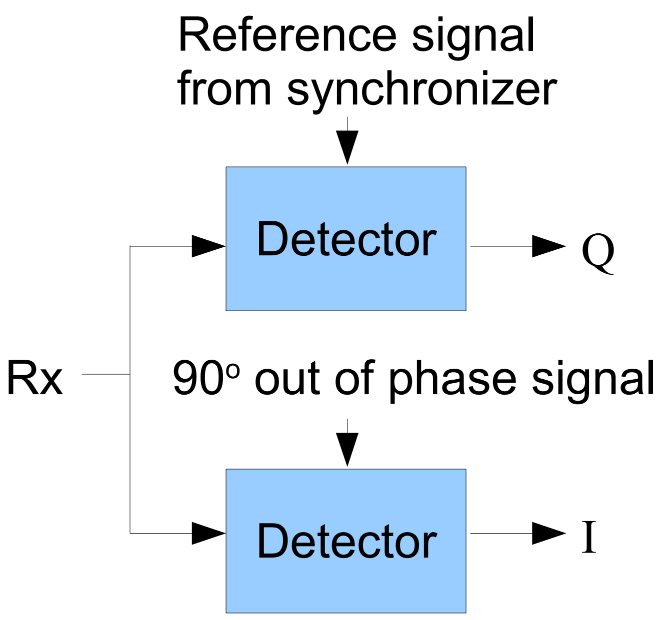
I and Q together give:

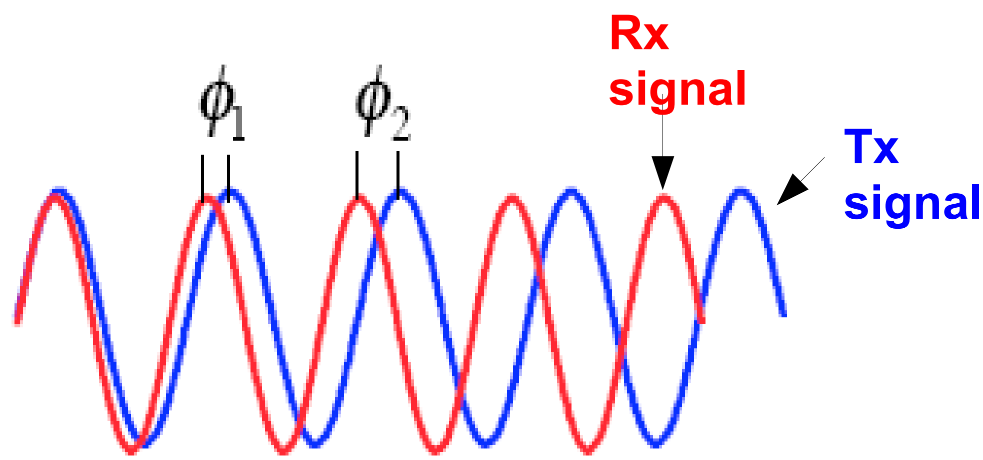
$$Sr(t) = a(t)e^{j\phi(t)}$$

So, the received signal is a time series of complex numbers

I/Q Demodulation

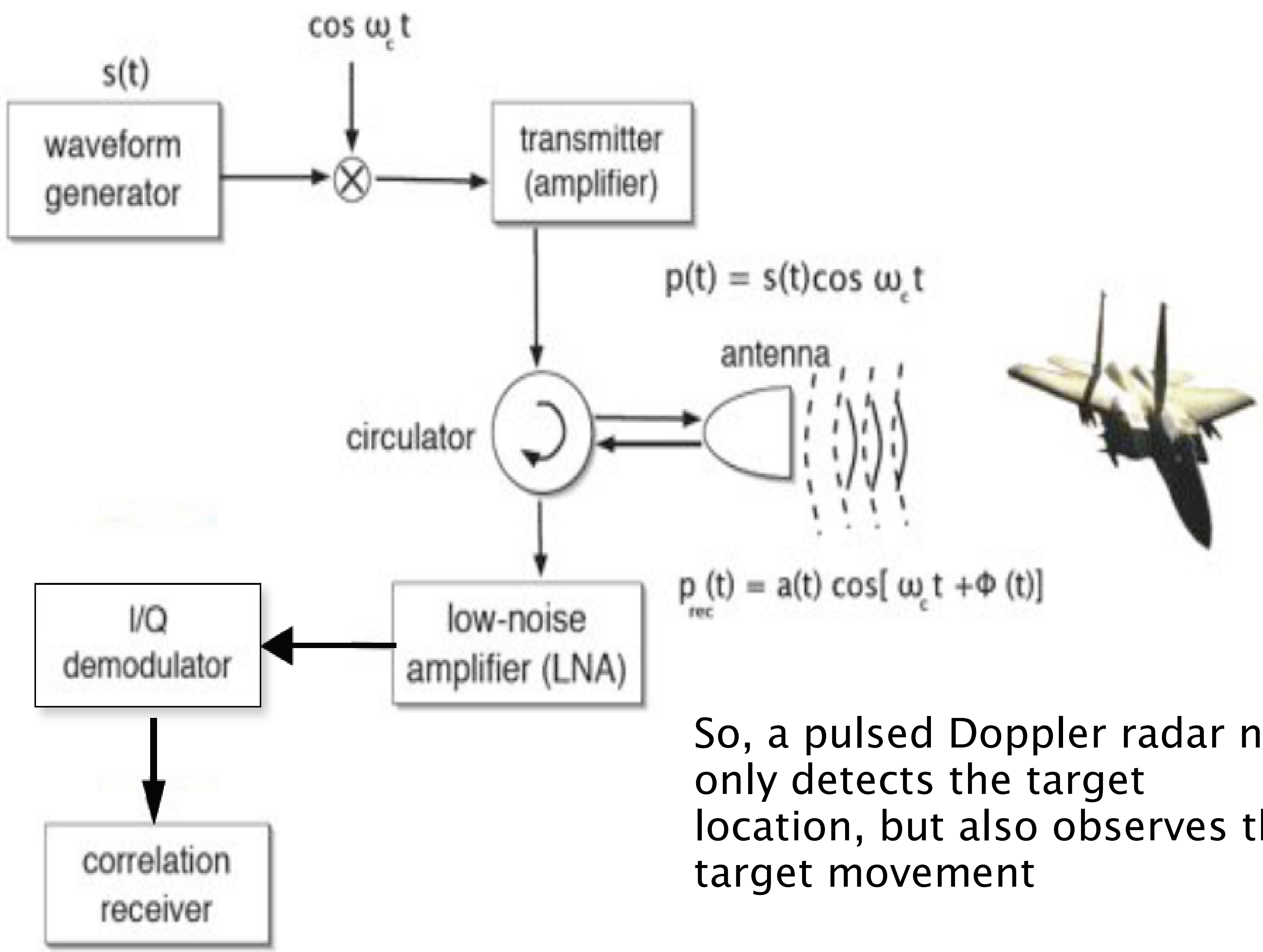






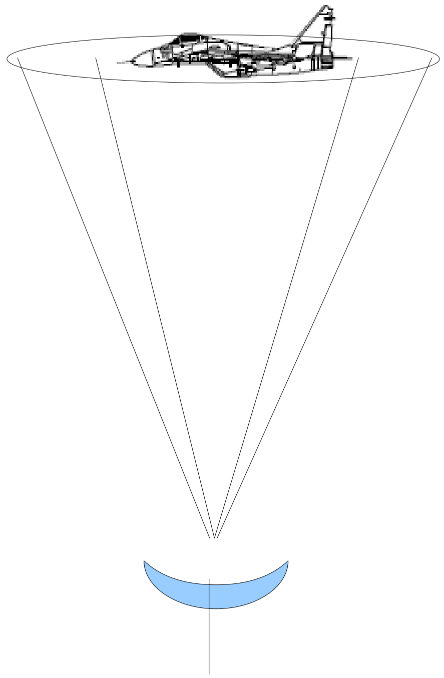
The Doppler frequency shows up as a pulse-to-pulse phase shift

Pulsed Doppler Radar system

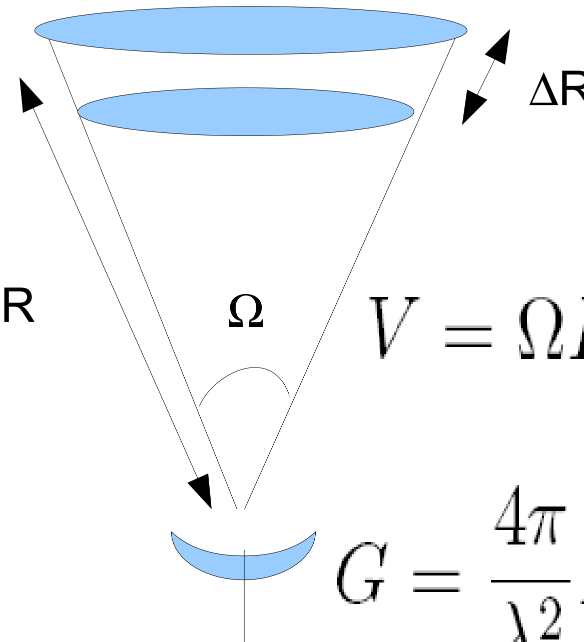


So, a pulsed Doppler radar not only detects the target location, but also observes the target movement

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 $10^{10} \times 10^{12} \times 10^{-28}$ = 10^{-6} m^2 !!)
  - CAN be measured by an incoherent scatter radar, which is why we are here.