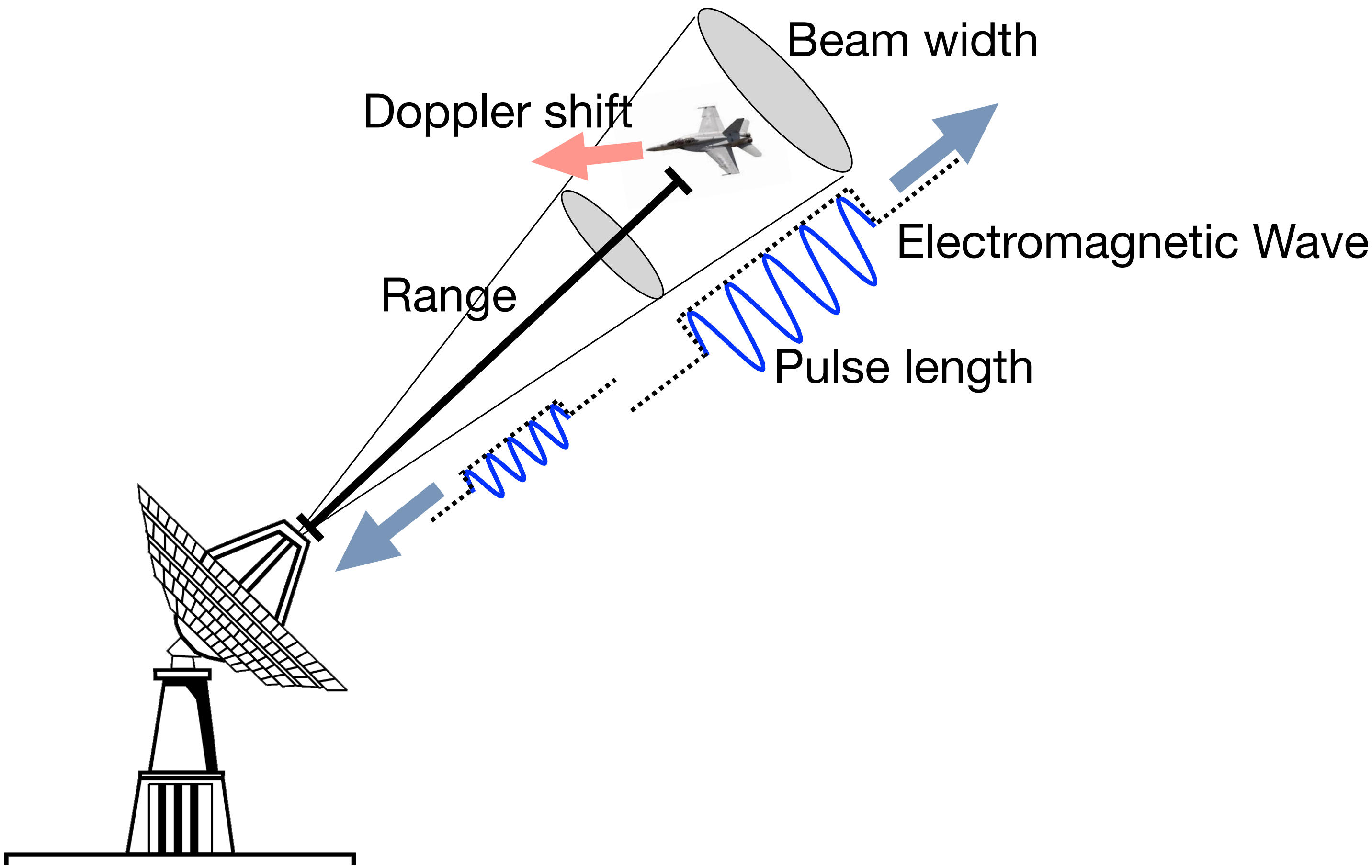
Radar Signal Processing: Part 1

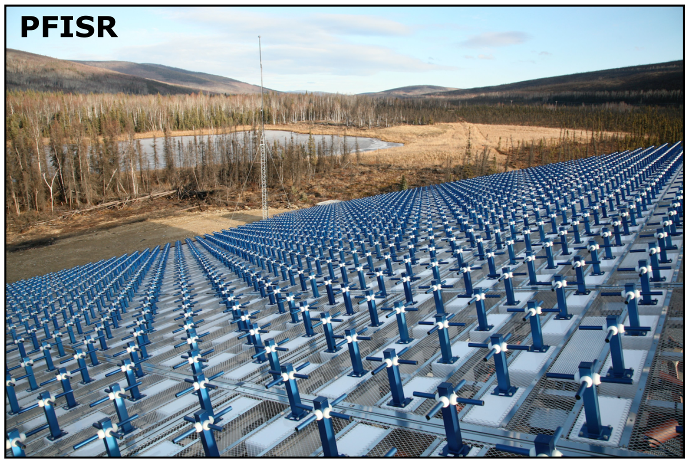
Basic Operation of a Pulse-Doppler Radar

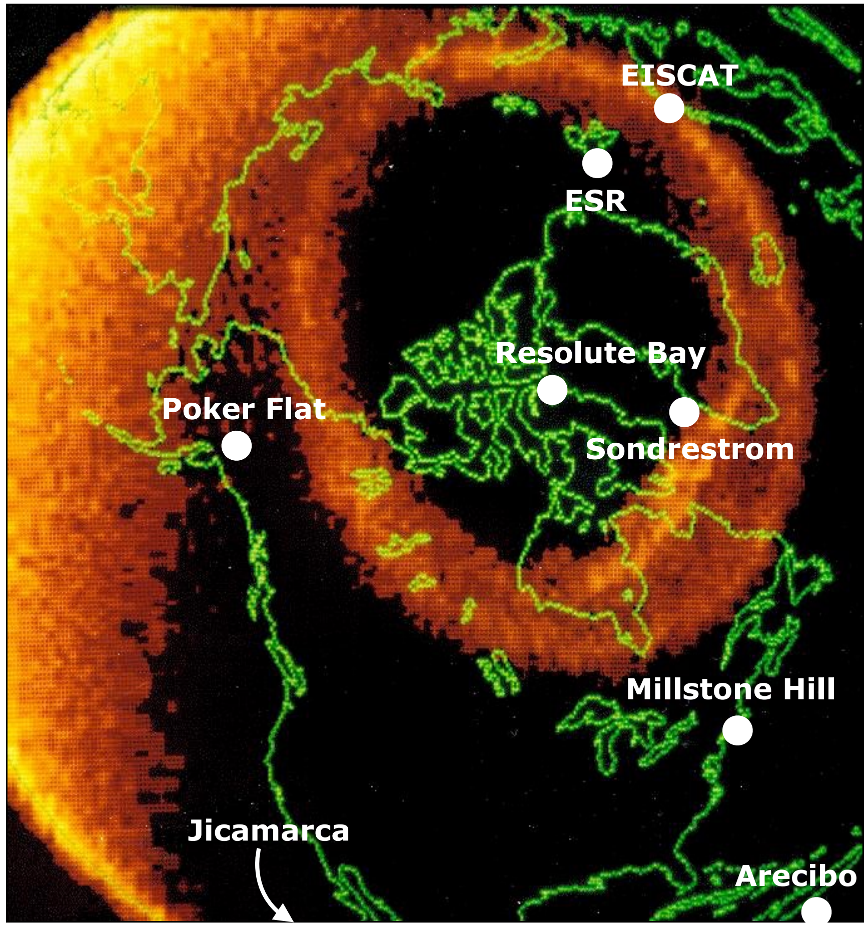
Josh Semeter
Boston University

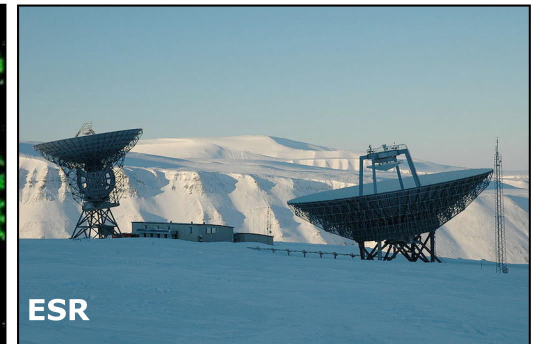
Pulse Doppler Radar

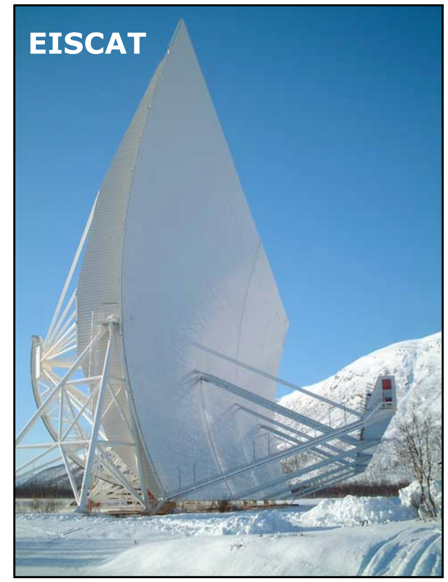


Incoherent Scatter Radar (ISR)





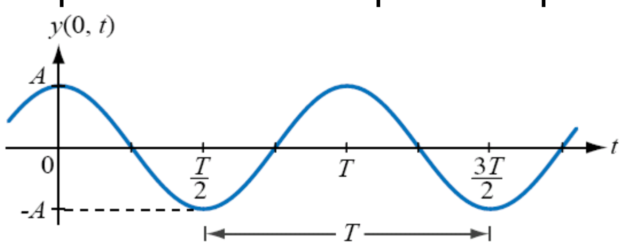




Traveling Waves

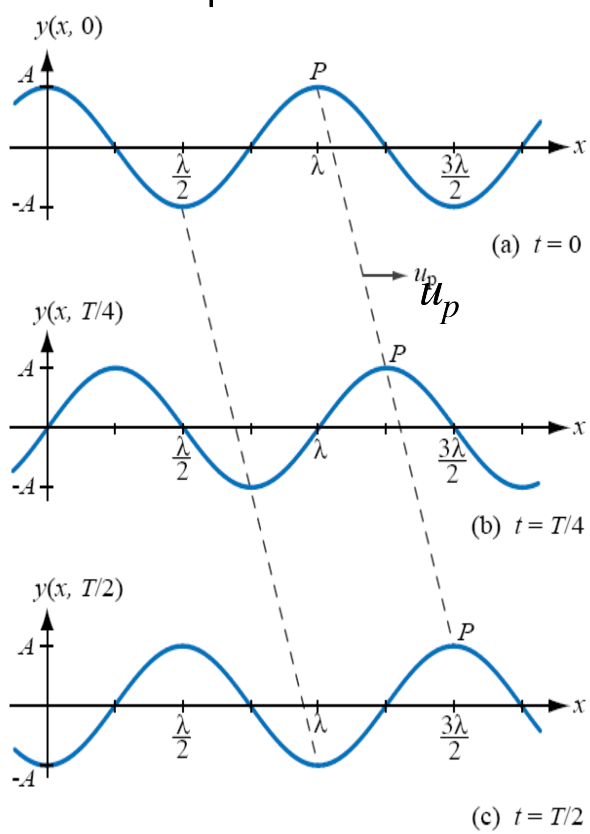
Traveling wave, 1D: $y(x,t) = A\cos(\omega t - kx)$
Angular velocity (radians/s): $\omega = 2\pi f = 2\pi/T$
Wave number (spatial frequency): $k = 2\pi/\lambda$
Phase velocity (c in a vacuum): $u_p = \omega/k$

Temporal variation at point in space:



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

Three snapshots in time:



The velocity of a point on the wave is found by by setting $\omega t - kx$ = constant. By taking the time derivative we obtain the ***phase velocity,***

$$u_p = \frac{dx}{dt} = \frac{\omega}{k}$$

The functional relationship between ω and k is called a ***dispersion relation.*** It appears ubiquitously in the study of wave phenomena

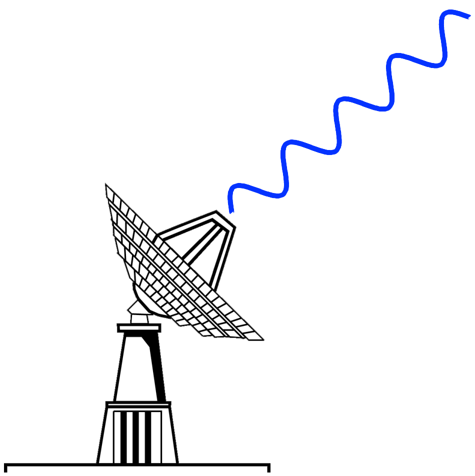
The simplest dispersion relation for an EM wave describes its propagation through free space,

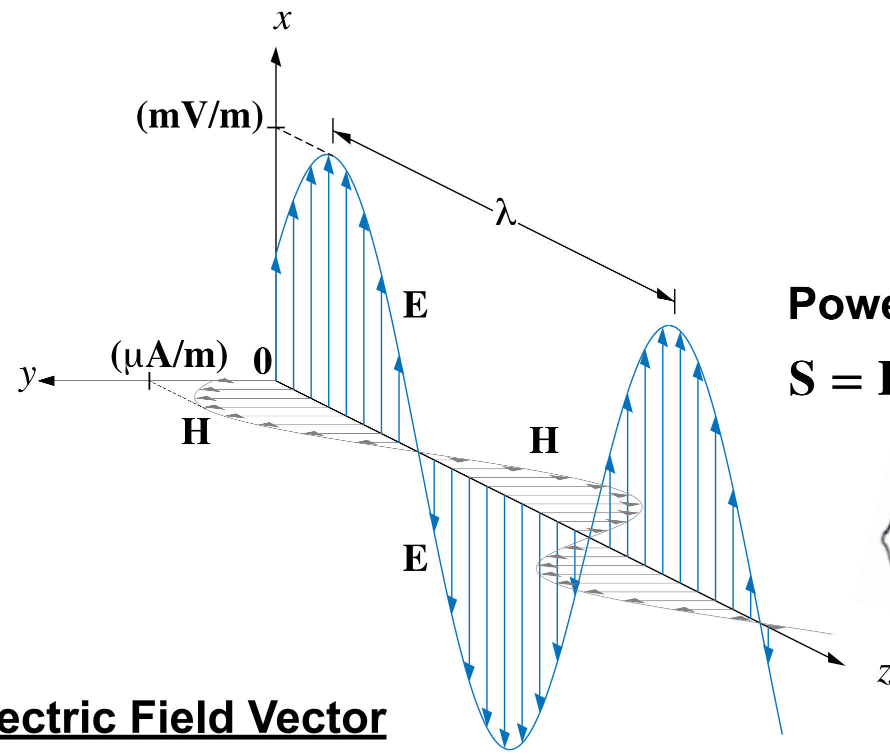
$$\omega = ck$$

where $c = 3 \times 10^8$ m/s. We will encounter more complicated dispersion relations soon!

Transverse Electromagnetic (TEM)

Radars transmit TEM waves and measure the scattered radiation from a target



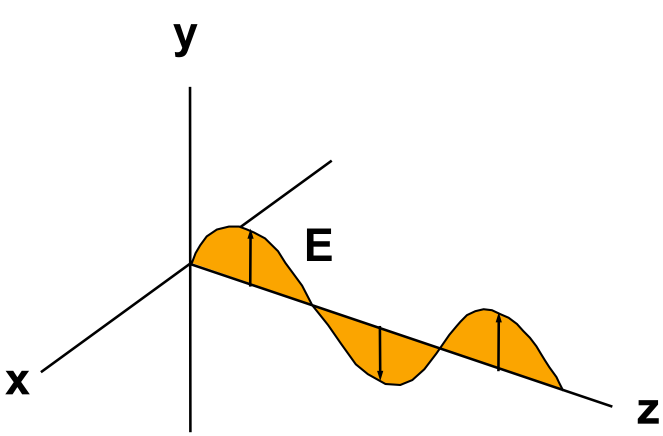


Power flow:

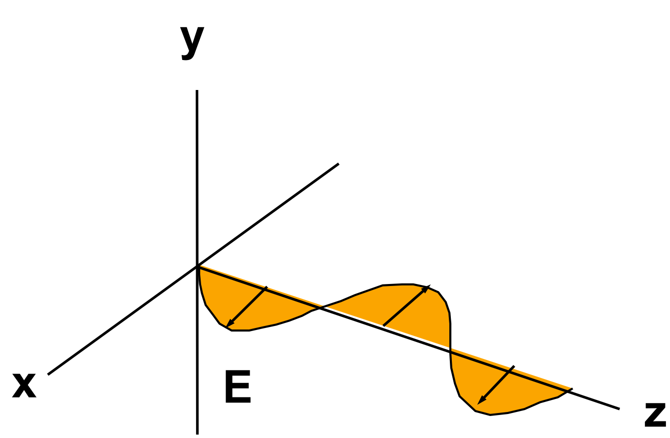
$\mathbf{S} = \mathbf{E} \times \mathbf{H}$ W/m^2

Polarization: Orientation of the Electric Field Vector

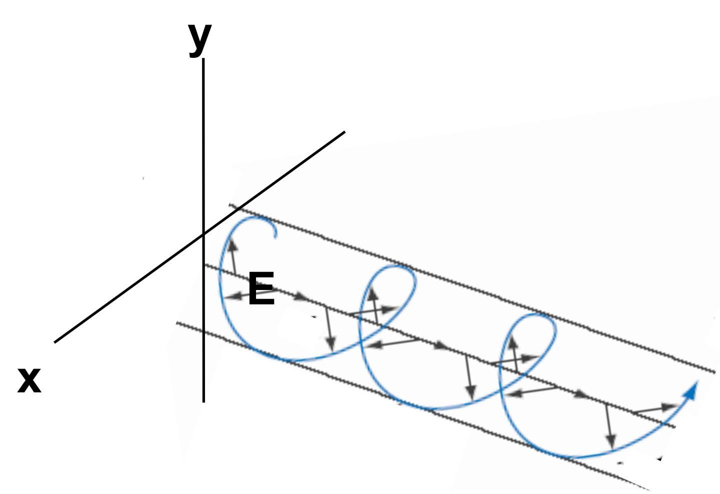
Vertical Polarization



Horizontal Polarization



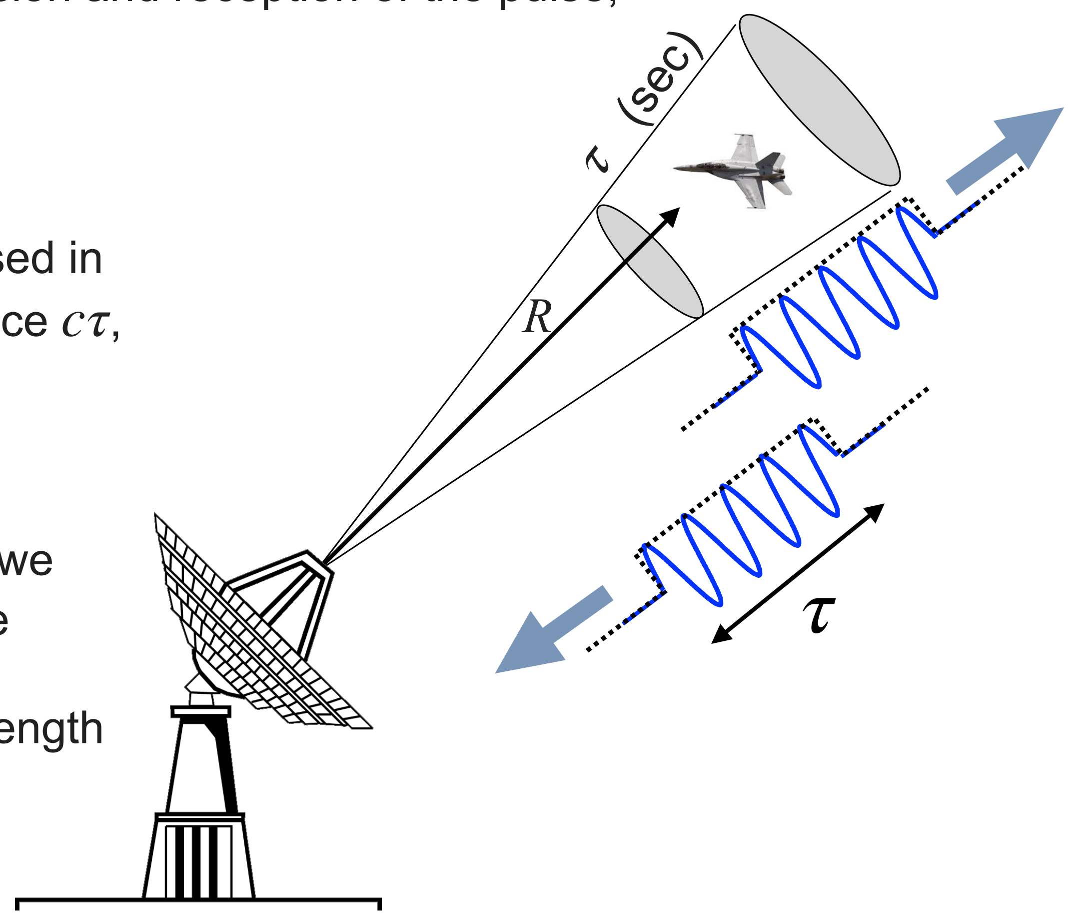
Circular Polarization



Range

Range R to the target is measured by transmitting a pulse of electromagnetic waves, and measuring the time Δt between transmission and reception of the pulse,

$$R = \frac{c\Delta t}{2}$$

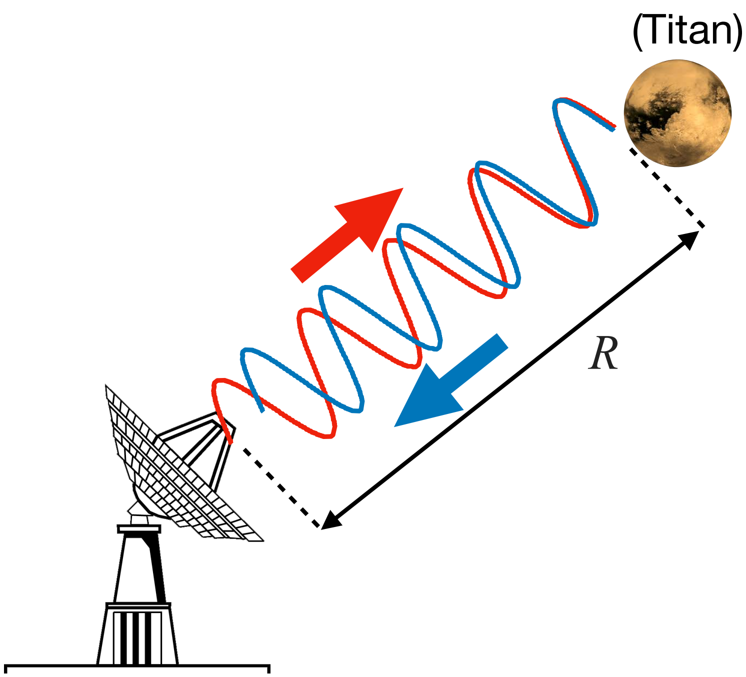


The ***pulse length*** τ is most often expressed in units of time, and corresponds to a distance $c\tau$, where $c = 3 \times 10^8$ m/s

Range resolution depends on how well we can resolve Δt. For the case of a simple on-off pulse, the optimal approach is to match the sampling period to the pulse length (the so-called "matched filter" approach).

Range resolution for a simple on-off pulse ("uncoded pulse") is controlled by τ. Shorter τ yields higher range resolution. But a shorter pulse also carry less total energy, and so the reflected signal is more difficult to discriminate from background noise.

Measuring Velocity



Assume a transmitted signal: $\cos(2\pi f_o t)$

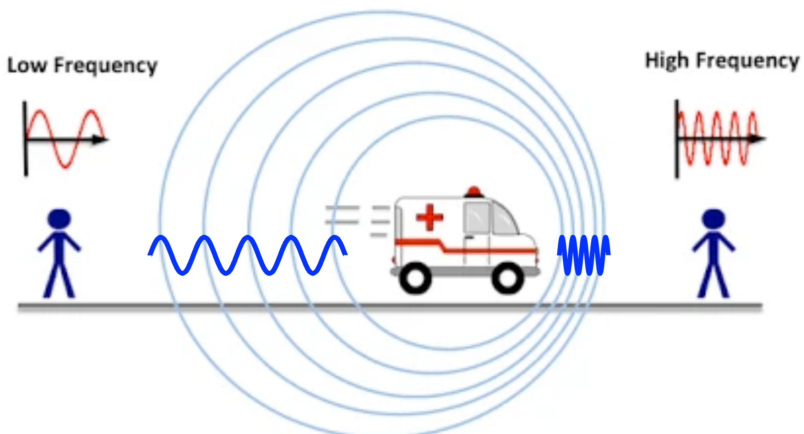
After return from target: $\cos\left[2\pi f_o\left(t+\frac{2R}{c}\right)\right]$

Now let us allow range *R* to vary with time. Let's assume the target moves at a constant velocity, with positive away from the radar and negative toward the radar:

$$R = R_o + v_o t$$

Substituting we obtain:

$$\cos\left[2\pi\left(f_o + \underbrace{f_o\frac{2v_o}{c}}_{-f_D}\right)t + \underbrace{\frac{2\pi f_o R}{c}}_{\text{constant}}\right]$$

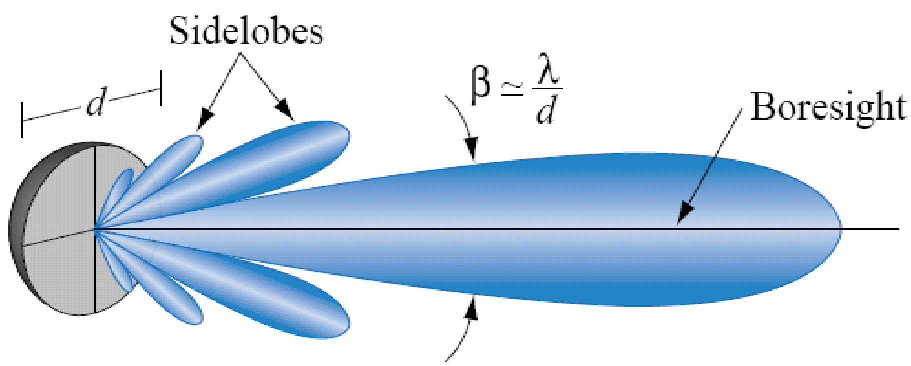


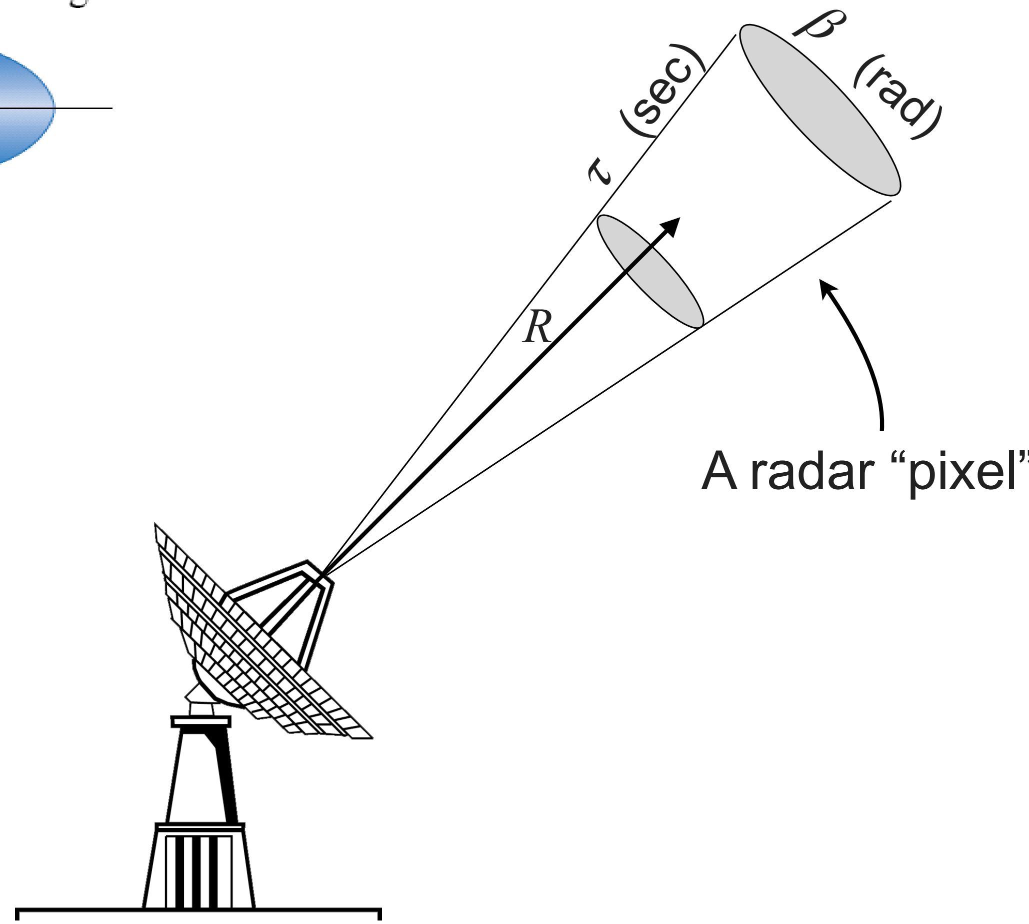
The shift in frequency caused by a moving target is proportional to the *component* of the velocity vector along the radar line of sight:

$$f_D = -\frac{2f_o}{c}v_o$$

How we determine f_D is left for other lectures.

Cross-range resolution (beam width)





The cross-range resolution is usually defined by the angular width of the main lobe of the antenna's power pattern. For a dish antenna this is approximately equal to the ration of the wavelength to the physical diameter,

$$\beta = \frac{\lambda_o}{d} \qquad \text{(radians)}$$

Millstone Hill ISR has a 46-m dish operating at a frequency of 440 MHz, or $\lambda = 0.68$ m, giving a beam width of $\beta \simeq 0.85^\circ$.

Doppler Radar Summary: "Coherent" hard targets

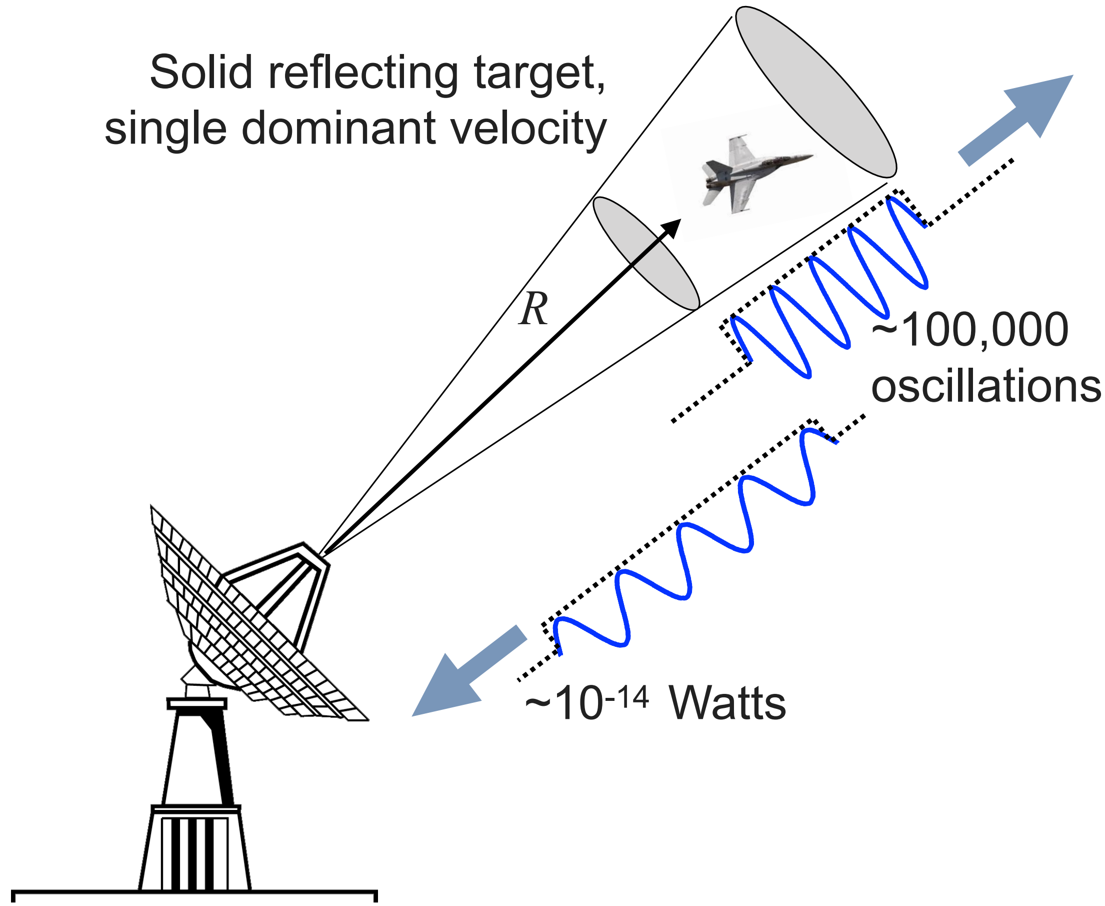
Two key concepts:

Time ⟺ Distance

$$R = -\frac{c\Delta t}{2}$$

Frequency ⟺ Velocity

$$f_D = -\frac{2f_o}{c}v_o$$



A Doppler radar measures backscattered power as a function range and velocity.
Velocity is manifested as a Doppler frequency shift in the received signal.

What happens when we have multiple targets in the radar volume, moving at different velocities?

Doppler Radar Summary: Distributed “Incoherent” Targets

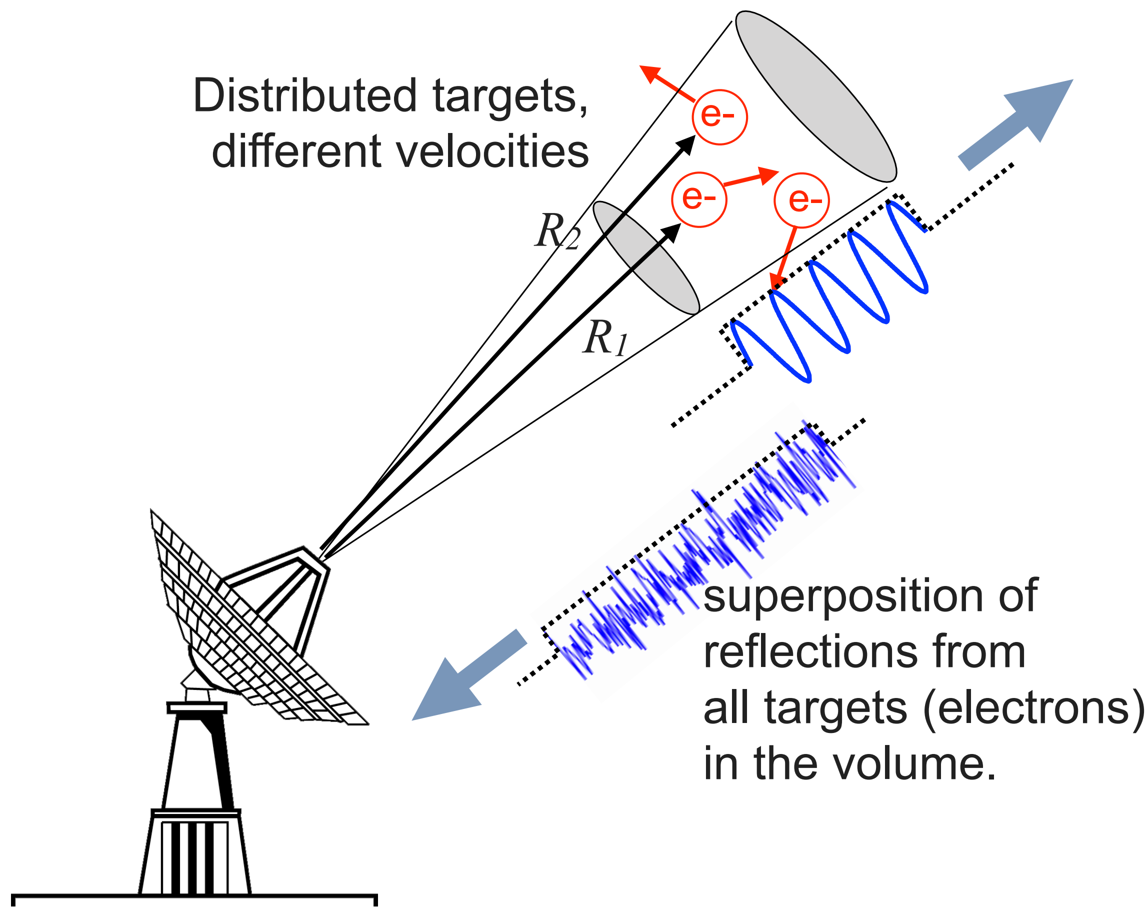
Two key concepts:

Time ⇔ Distance

$$R = -\frac{c\Delta t}{2}$$

Frequency ⇔ Velocity

$$f_D = -\frac{2f_o}{c}v_o$$



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