ECE 215
Objective 3.8
Pulse Doppler Radar

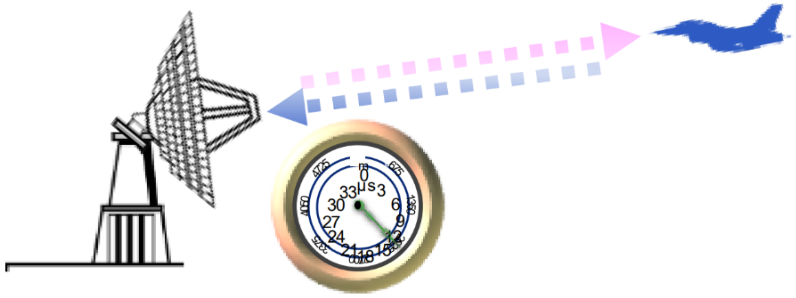
Material Contribution from MIT/LL Radar Short Couse

Objective 3.8

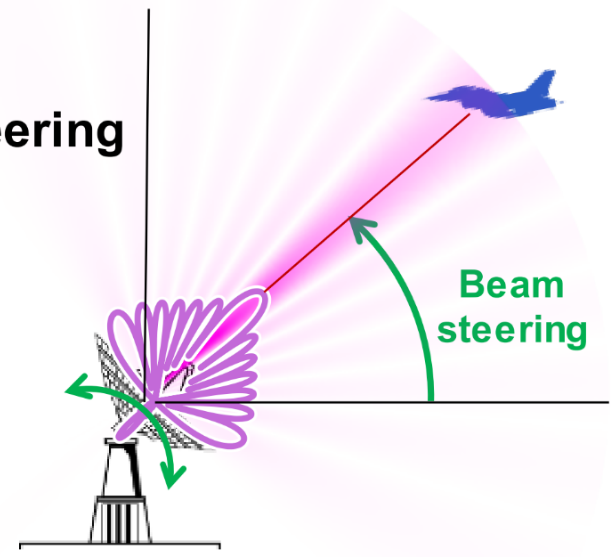
I can calculate the range resolution, unambiguous range, and a target's velocity for pulse Doppler radar.

What Can Radars Measure?

- What can radars measure?
  - **Range** (by measuring time)

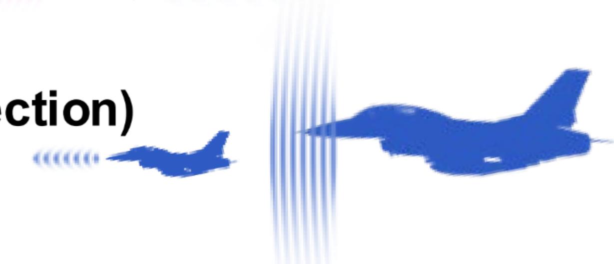


  - **Angle** (by steering beam)

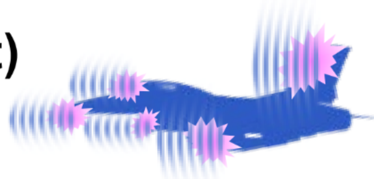


  - **Velocity** (by observing Doppler frequency shift)

  - **Size** (by measuring the strength of the reflection)

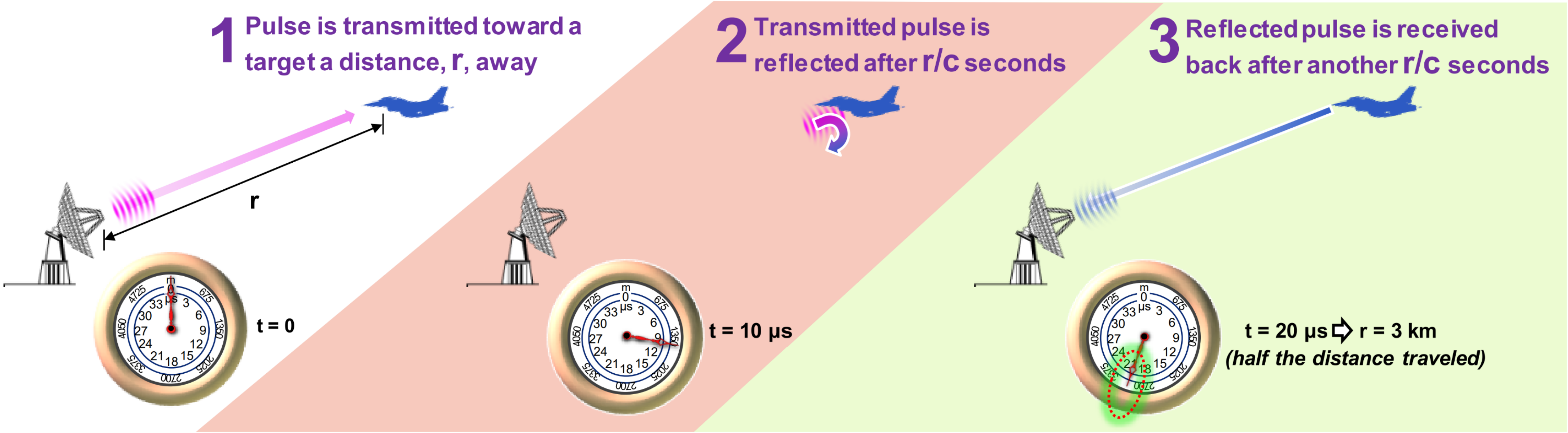


  - **Features** (by measuring differences in reflections across distinct parts of a target)



Key Principle of Radar: Elapsed Time

- **TIME for a pulse to travel to a target and back is proportional to DISTANCE**



Since total distance traveled is the elapsed time multiplied by the speed of light

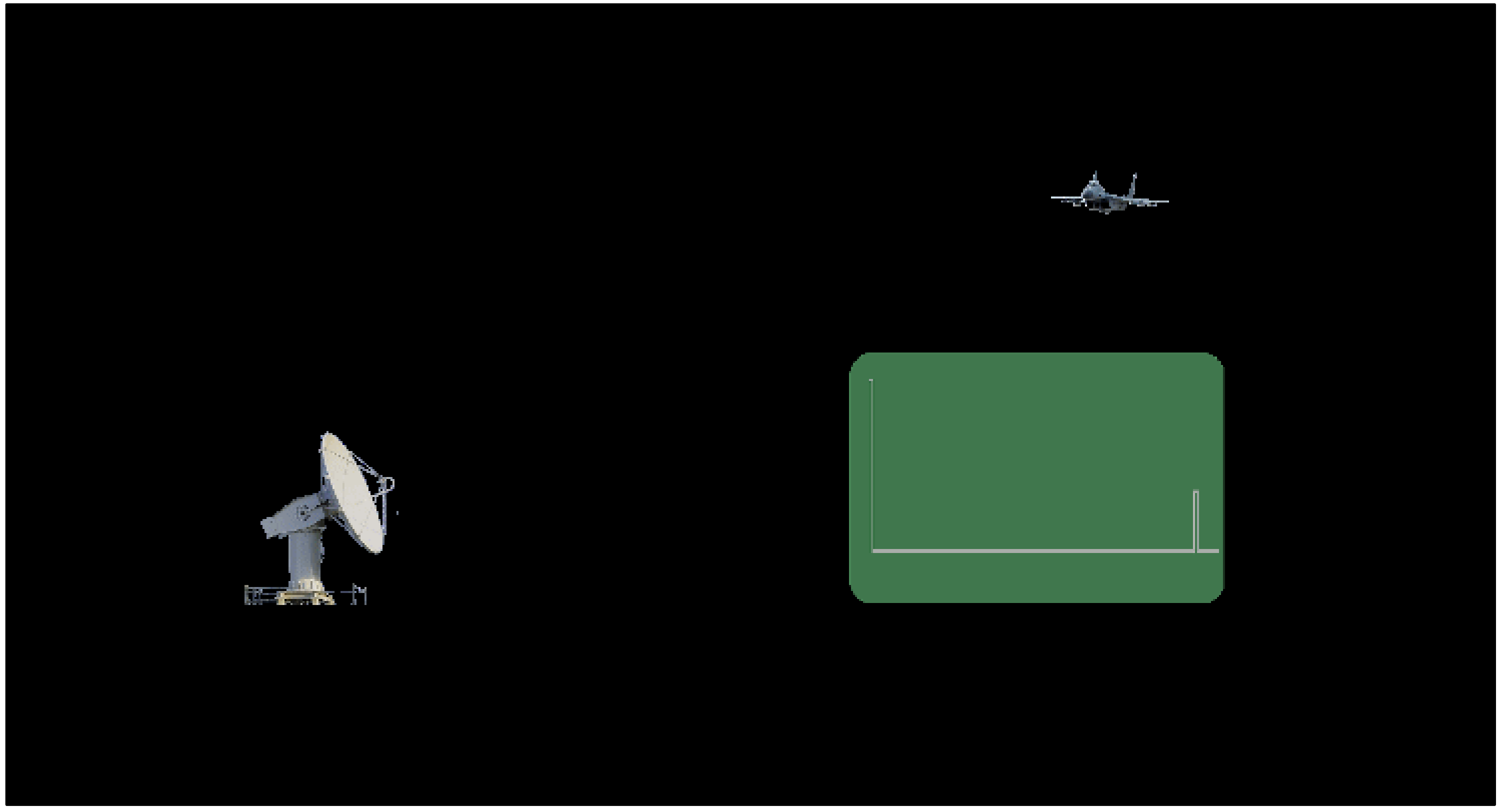
$$\text{Range} = \text{Time}_{\text{Roundtrip}} \frac{c}{2}$$

Speed of Light (pointing to c)

Speed of electromagnetic energy through free space

~3x10^8 m/s

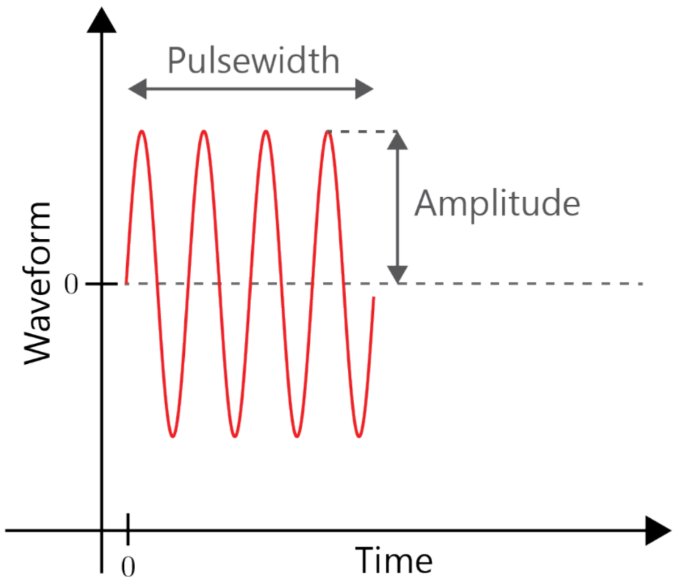
Radar Challenges



- From a single radar, it is possible to transmit and receive signals using the same antenna.
- However, a challenge arises: the system must alternate between transmitting and receiving, leading to periods where it must stop transmitting to listen for a return signal.
- Potential solutions include sending out pulses and waiting for the return signal (monostatic radar) or using a secondary, separate location for receiving signals (bi-static radar).

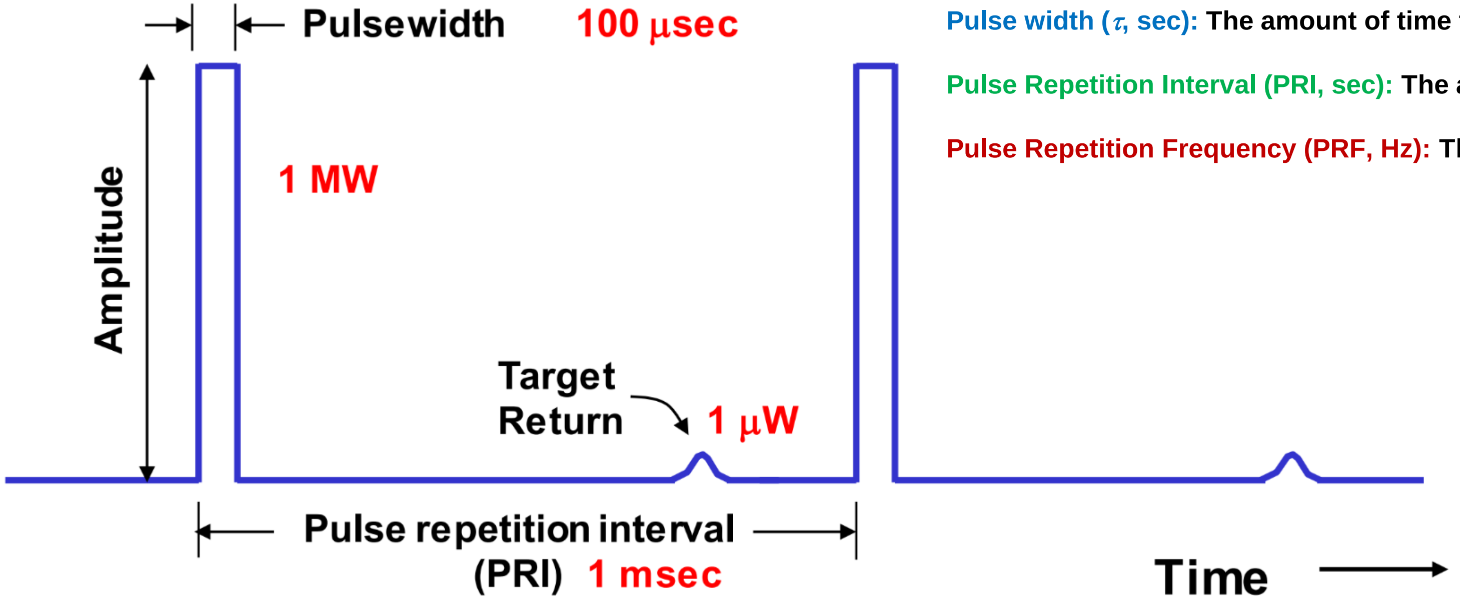
Waveform

- *Waveform* is the shape of the wave emitted from the radar
- Typically, a pulsed (i.e., time-limited) sine wave or variant



- Pulsewidth (or duration) and amplitude determine amount of transmit energy
  – Longer pulsewidth, larger amplitude means more transmit energy

Waveform Terminology



Pulse width (τ, sec): The amount of time that the radar transmits a pulse

Pulse Repetition Interval (PRI, sec): The amount of time between pulse transmission

Pulse Repetition Frequency (PRF, Hz): The number of pulses transmitted per second

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

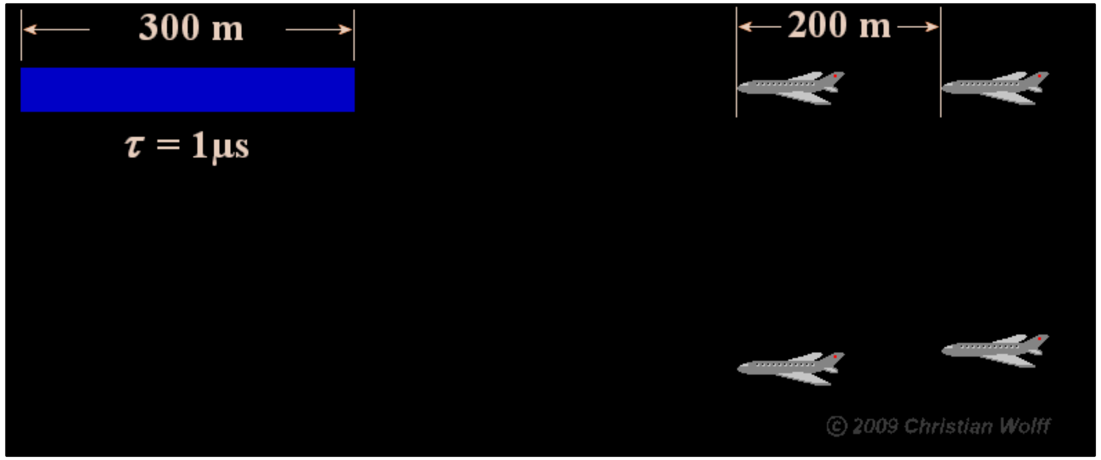
$$\text{Pulse repetition frequency (PRF)} = 1/(\text{PRI}) \qquad 1\ \text{kHz}$$

Range Resolution

- Range resolution is the ability of a radar system to distinguish between two or more targets that are close to each other in distance.
- It defines the minimum separation in range (distance) that two targets must have to be detected as separate objects.
- The range resolution is primarily determined by the radar pulse width (duration of the transmitted pulse); shorter pulses result in better (finer) range resolution.

$$\Delta R = \frac{c(\tau)}{2}$$

ΔR – Radar Range Resolution
τ – Pulse width



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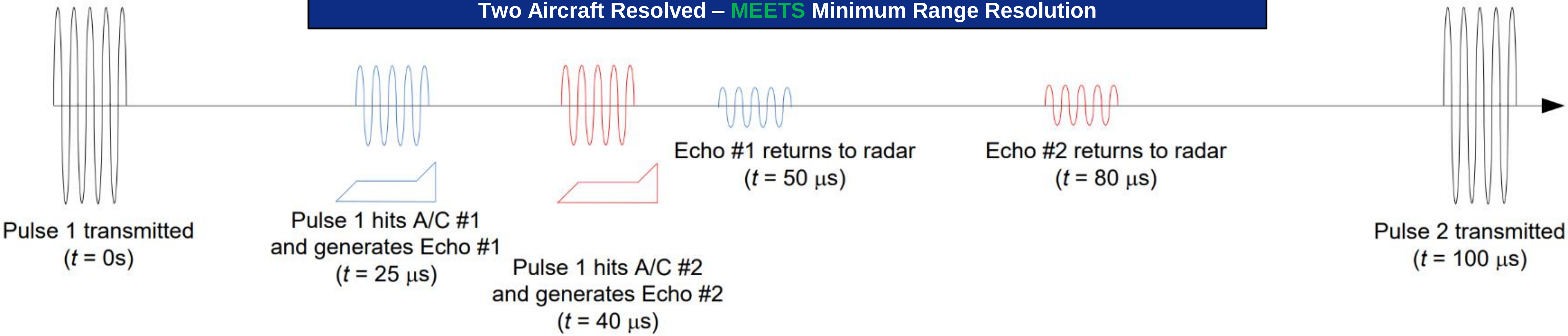
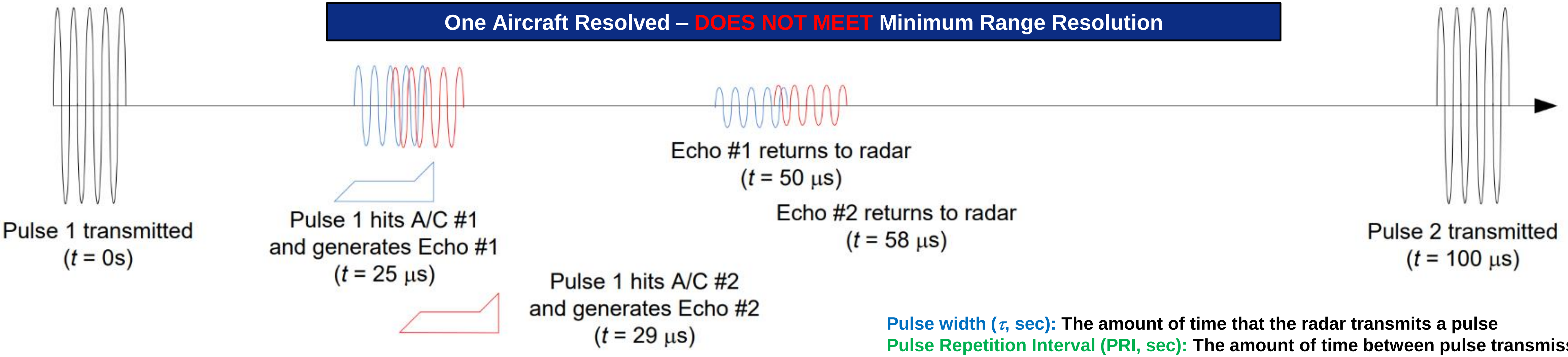
Range Resolution

Two Aircraft Resolved – MEETS Minimum Range Resolution



One Aircraft Resolved – DOES NOT MEET Minimum Range Resolution



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Example 1

- Two planes are separated by 500m. If your RADAR has a pulse width of 1μs, can you see both planes? What if the pulse width was 10μs?

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$$\Delta R = \frac{c\tau}{2} = \frac{\left(3 \times 10^8 \frac{m}{s}\right) \times (1\mu s)}{2} = 150m \rightarrow Yes!$$

$$\Delta R = \frac{c\tau}{2} = \frac{\left(3 \times 10^8 \frac{m}{s}\right) \times (10\mu s)}{2} = 1.5km \rightarrow No!$$

Unambiguous Range

- The maximum unambiguous range for a RADAR is the maximum range at which a RADAR can both detect two objects and differentiate between them.

- Range ambiguity occurs when a reflection from an object takes longer to return than the Pulse Repetition Interval (PRI).

$$R_{unamb} = \frac{c(PRI)}{2}$$

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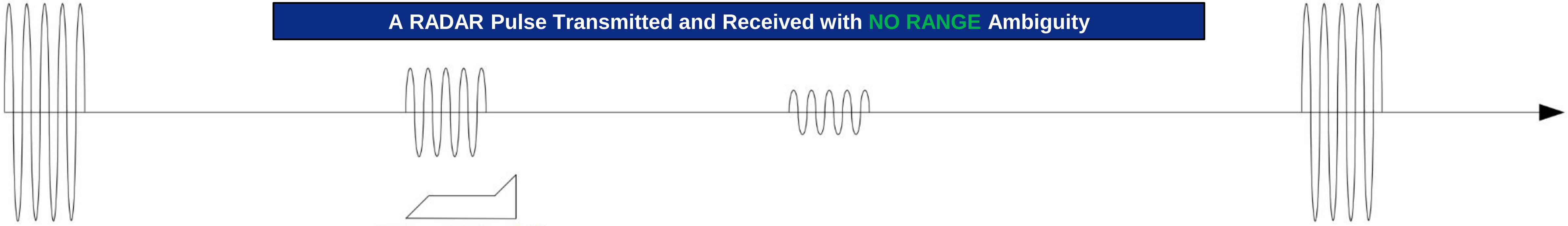
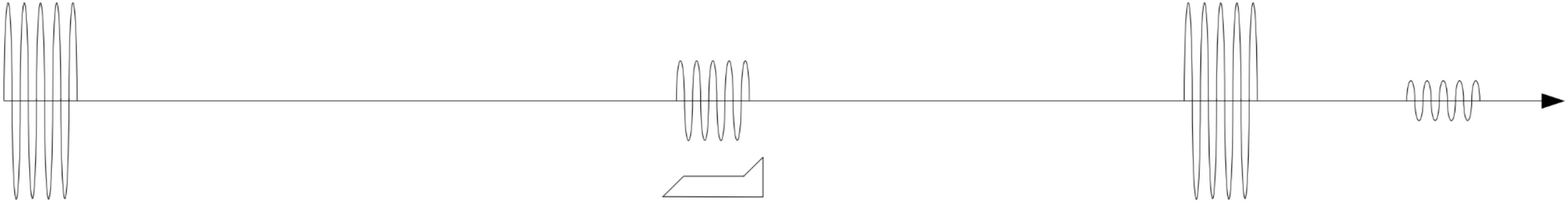
Unambiguous Range

A RADAR Pulse Transmitted and Received with NO RANGE Ambiguity



A RADAR Pulse Transmitted and Received with WITH RANGE Ambiguity



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Example 2

- A RADAR that has a PRF of 10kHz is trying to detect an object that is 25km away. Will it be able to unambiguously detect the range?

- **A RADAR that has a PRF of 10kHz is trying to detect an object that is 25km away. Will it be able to unambiguously detect the range?**

$$PRI = \frac{1}{PRF} = \frac{1}{10000} = 100\mu s$$

$$R_{unamb} = \frac{c(PRI)}{2} = \frac{\left(3 \times 10^8 \frac{m}{s}\right)(100\mu s)}{2} = 15km \rightarrow No!$$

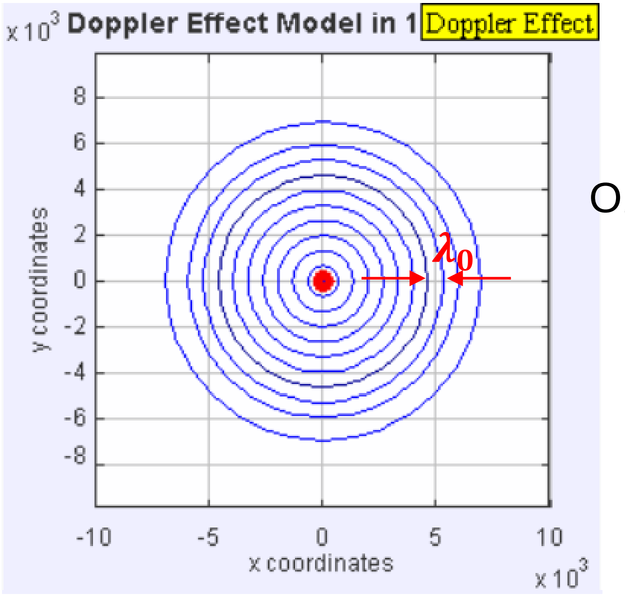
For ground radar, the PRF is set so the unambiguous range($R_{\max\ unamb}$) is <u>equal</u> to the maximum LOS range(R_{LOS}) to prevent ambiguities.

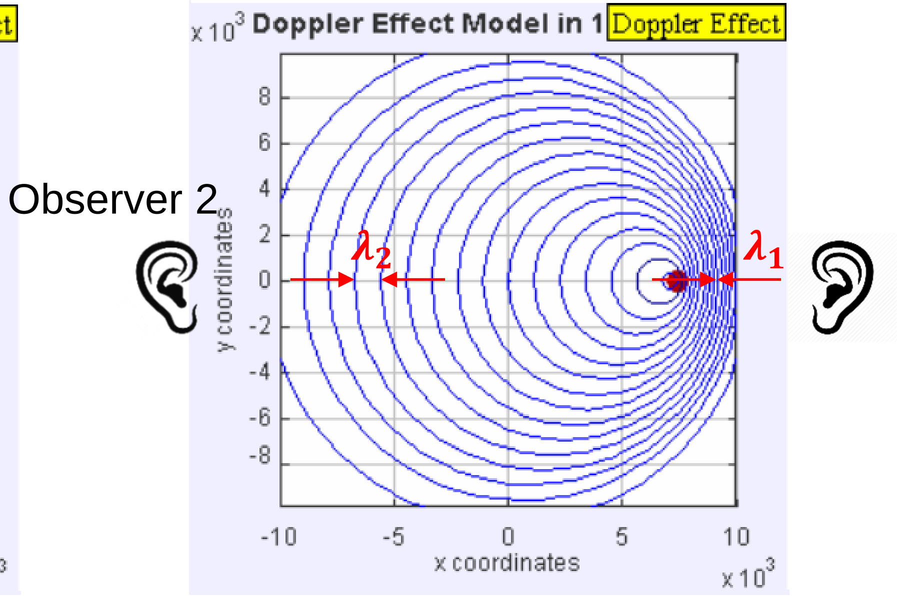
$$\boxed{R_{LOS} = \sqrt{2h}}$$

From Lesson 31

Doppler Effect

- **Frequency of wave emitted or reflected from moving target will be slightly higher or slightly lower than the original frequency. This is called *<u>Doppler Shift.</u>***





When target approaches ⟹ $f_{received} > f_{transmitted}$

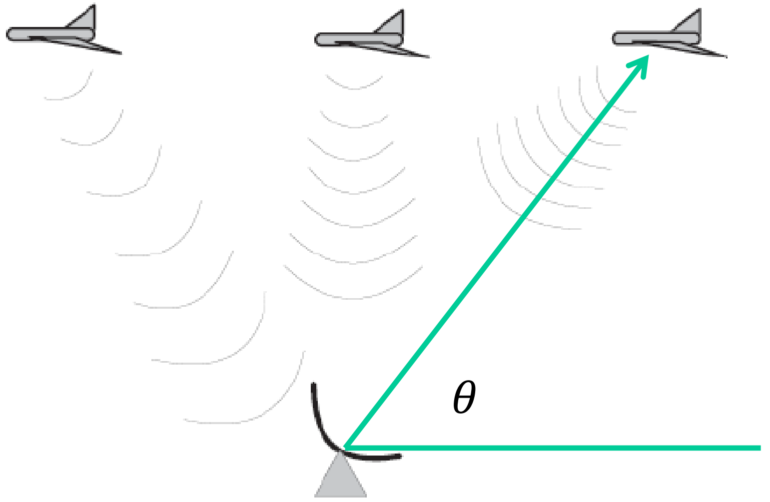
When target moves away ⟹ $f_{received} < f_{transmitted}$

Target Speed & Doppler Shifts

- A reflected RADAR pulse will have a frequency that is shifted from the reference pulse
- The shift is proportional to the speed of the target.
- "Flying the notch" is a tactic used by aircraft to evade detection or tracking by radar systems using Doppler radar. This maneuver involves flying at a specific angle, usually perpendicular (90 degrees) to the radar source.

$$f = f_0 \left[1 \pm \frac{2v\cos\theta}{c} \right]$$

- *f_0 is the original RADAR frequency*
- *v is the target velocity*
- *c is the speed of light*
- *θ is the approach angle*
- *Positive for a closing target*
- *Negative for a fleeing target*



Example 3

- An aircraft is approaching a RADAR using an approach angle of 20o. The aircraft is traveling at a speed of 200 mph. The RADAR emits its signal at a frequency of 200 MHz. What is the frequency of the return signal?

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$$\mathbf{200\ mph \times 1.61\frac{km}{mi} \times 1000\frac{m}{km} \times \frac{1\ hour}{3600\ s} = 89.44\ m/s}$$

$$\mathbf{f = f_0\left[1 + \frac{2v\cos\theta}{c}\right] = (200 \times 10^6\ Hz)\left[1 + \frac{2(89.44\ m/s)\cos(20°)}{3 \times 10^8\ m/s}\right] = 200.0001121\ MHz}$$