ECE 215

Objective 3.7

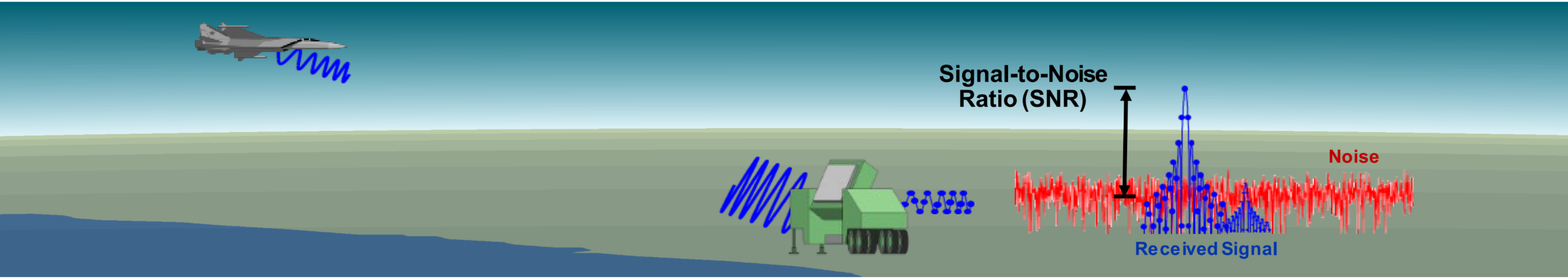
Detection Range using Radar Range Equation

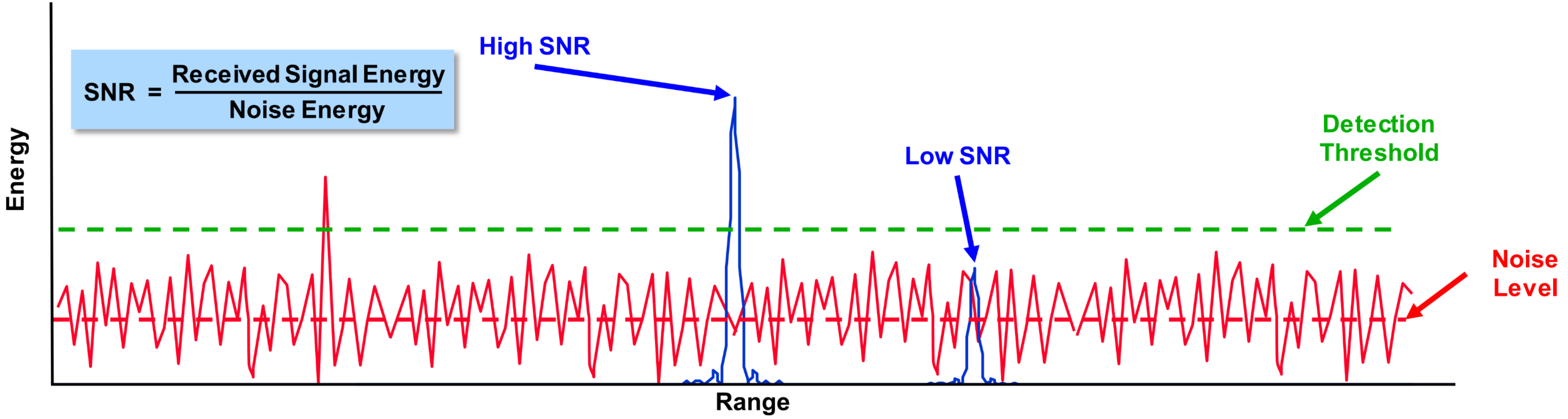
Material Contribution from MIT/LL Radar Short Couse

Objective 3.7

I can calculate the maximum detection range from a radar antenna to a target using the radar range equation.

Detection of Signals in Noise



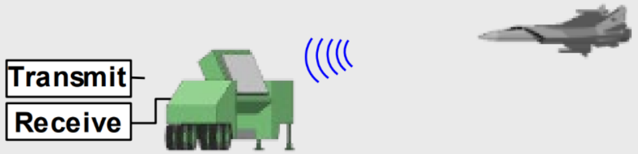


Developing the Radar Range Equation

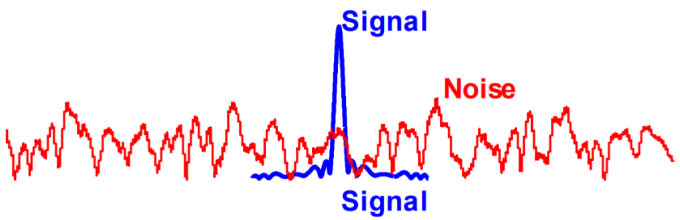
Step 1: Radar emits energy toward target

Step 2: Radiation scatters from target

Step 3: Scattered radiation received by radar

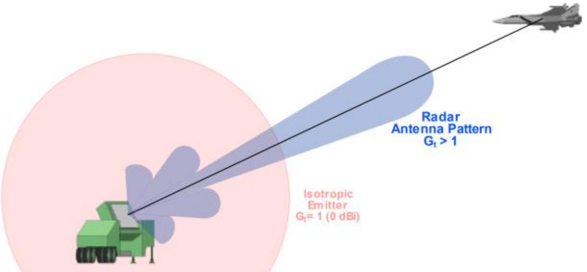


Step 4: Signal exceeds noise for detection

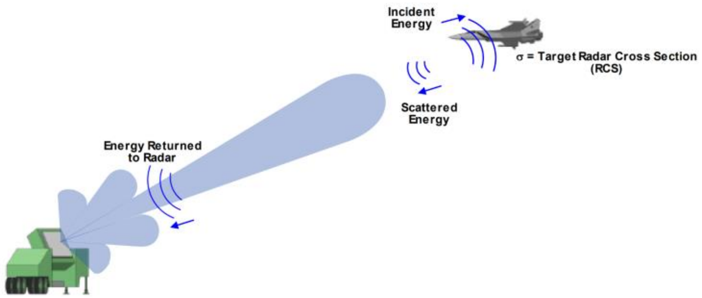


Radar range equation composed of factors describing each step

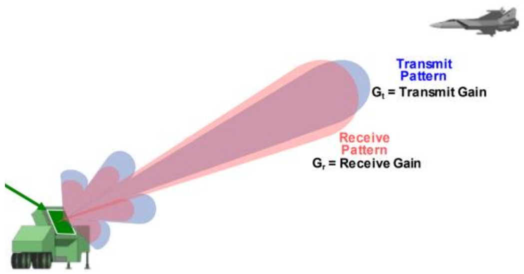
Radar Equation



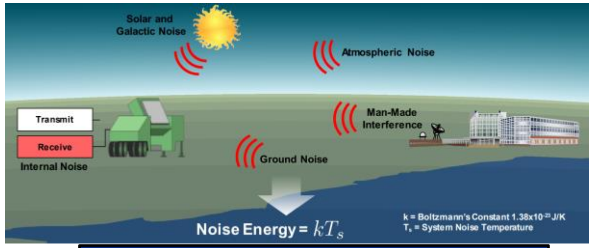
Radar Emits Energy to Target with Gain



Radiation Scatters from Target



Power Received by the Radar (Assume Same Gain in ECE 315)



Noise and Interface

P_T: The power sent by the transmitting antenna (in Watts)
G_T: The gain of the RADAR (transmits and receives) (unitless)

RCS: RADAR Cross Section of target (in meters squared)
λ: The wavelength of the RADAR signal (in meters)
R: The distance between the RADAR and target (in meters)

P_R: The power collected by the receiving antenna (in Watts)

$$P_R = P_T {G_T}^2 RCS \frac{\lambda^2}{(4\pi)^3 R^4}$$

Radar Cross Section (RCS) σ

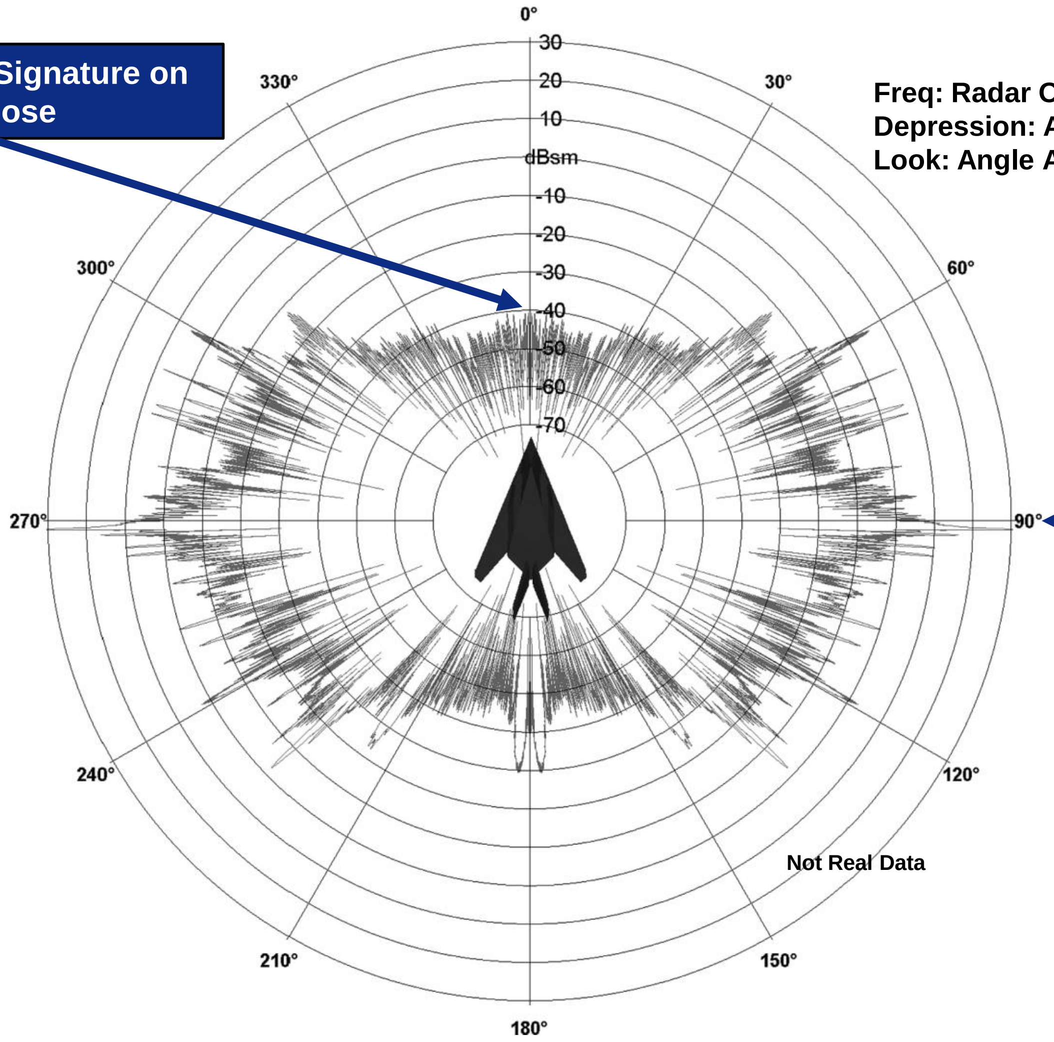
- **Radar Cross Section (RCS) is a measure of how much a target reflects radar signals back to the radar receiver. It quantifies the detectability of an object by radar and is expressed in square meters (m^2).**
- **RCS depends on the size, shape, material, and orientation of the target relative to the radar**
- **A smaller RCS indicates a weaker return signal, making the object less detectable.**
- **Untold resources spent on reducing, measuring, and controlling RCS to secure our advantage and access worldwide.**

Radar Cross Section Polar Plot

Reduction in Signature on the Nose

Freq: Radar Operating Frequency
Depression: Angle Downward
Look: Angle Around Aircraft

Low Observable Aircraft are Specifically Tuned to a Specific Threats (Freq) and Mission Type (A-to-A, A-G, ISR)



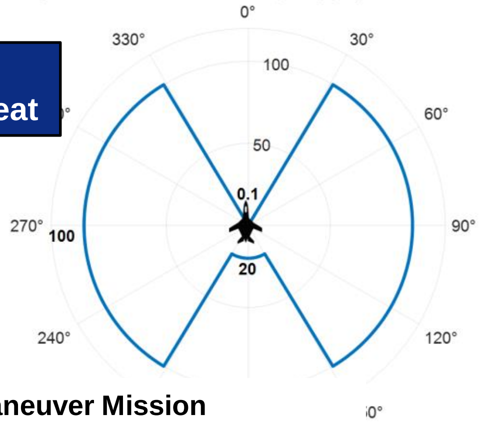
Energy Must Be Conserved Spike Management is Key

RCS Must Be Known or Calculated for All Radar Threats (Freq), Ranges (Depression/Look)

Mini-Project #2 Polar Plot Examples

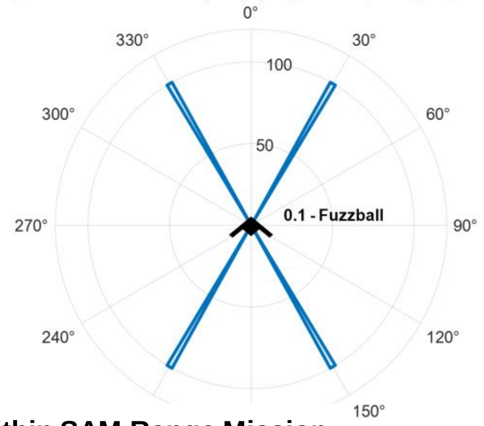
X-Band Missile Defeat

Loyal Wingman, Radar Cross Section (RCS) (m^2), X-Band, Co-Altitude

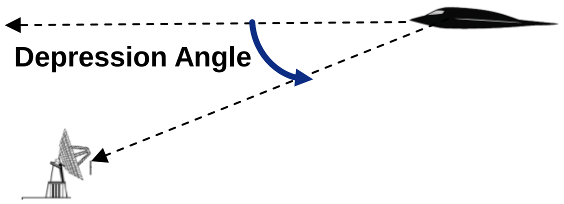


- Shoot – Maneuver Mission
- “Pacman” RCS

B-21, Radar Cross Section (RCS) (m^2), X-Band, 5 Deg Depression



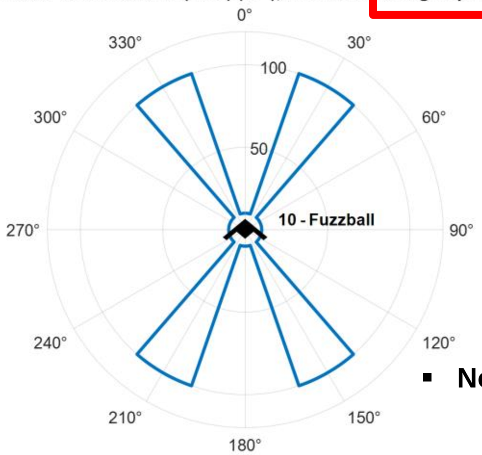
- Bombs within SAM Range Mission
- All Aspect RCS



Depression angle **refers to the angle between the horizontal plane and the line of sight from the bottom of the aircraft to the threat radar.**

“*Fuzzball*” is an informal term referring to the average Radar Cross Section (RCS) of an aircraft when integrated over all aspect angles.

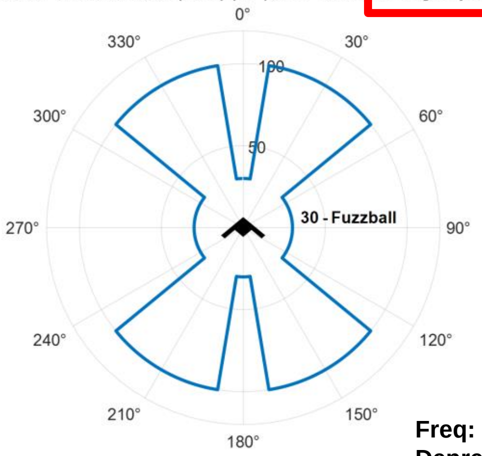
B-21, Radar Cross Section (RCS) (m^2), VHF-Band 5 Deg Depression



VHF-Band Long Range Detection Defeat

- No Detection Mission
  - All Aspect RCS

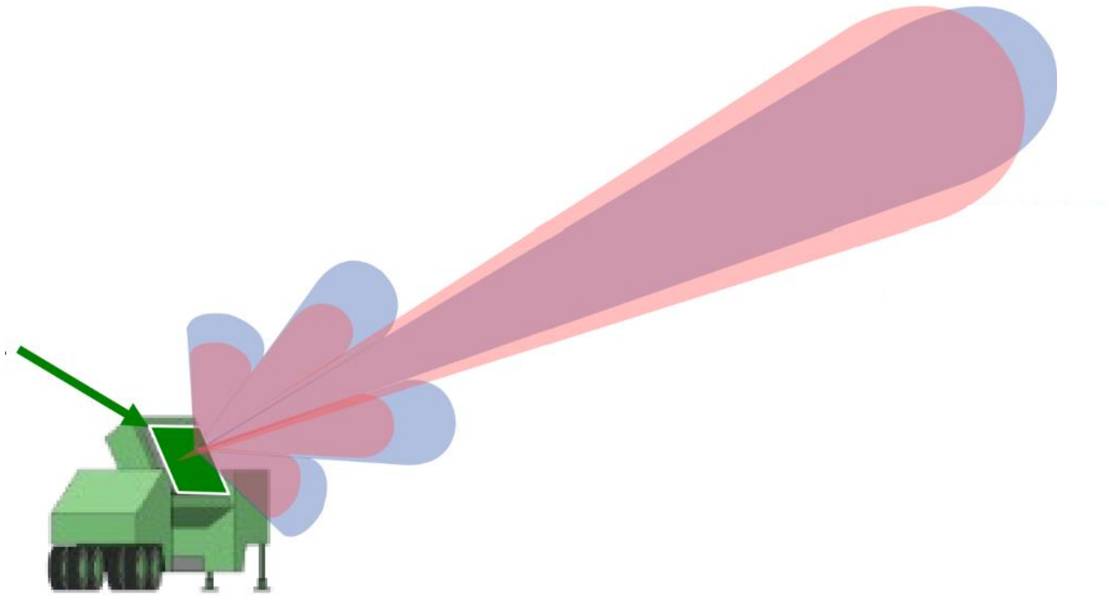
B-21, Radar Cross Section (RCS) (m^2), VHF-Band 20 Deg Depression



Freq: Radar Operating Frequency
Depression: Angle Downward
Look: Angle Around Aircraft

Radar Cross Section (RCS) is highly dependent on mission-specific parameters within three-dimensional space. It varies as a function of the platform's orientation relative to the threat radar and the vehicle's physical configuration.

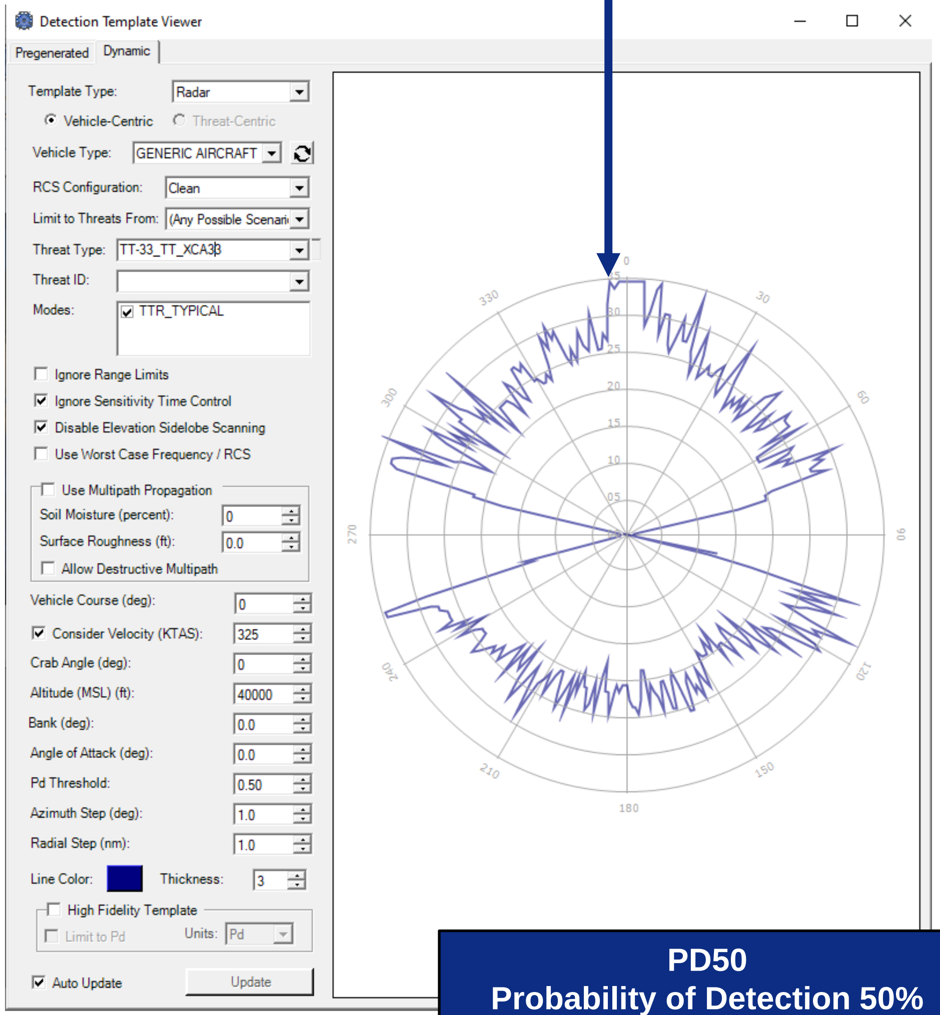
Detection Range



Detection Range

$$R = \sqrt[4]{P_T G^2 RCS \frac{\lambda^2}{(4\pi)^3 P_R}}$$

Modeled Range for Detection for Specific Threat



PD50
Probability of Detection 50%

Radar Example

- **A UAS is flying at 800 ft AGL searching for an 18 ft tall drug running ship which has an RCS of 40 m2. The RADAR transmits 1kW at 200 MHz and has an antenna with a gain of 100. The UAS needs to receive at least 19 fW to detect a target. What is the max distance for the UAS to detect the boat?**

Radar Example

Solution

- A UAS is flying at 800 ft AGL searching for an 18 ft tall drug running ship which has an RCS of 40 m2. The RADAR transmits 1kW at 200 MHz and has an antenna with a gain of 100. The UAS needs to receive at least 19 fW to detect a target. What is the max distance for the UAS to detect the boat?

Height Station ($h_{Station}$)	$18\ ft$
RCS	40 m^2
Frequency (f)	$200\ MHz$
Height UAS (h_{UAS})	$800\ ft$
Antenna Gain (G_R)	100
Min Receive Power ($P_{R,min}$)	19×10^{-15} W
Power Transmitter (P_T)	1 kW

$$r_{max,LOS} = \sqrt{2h_{UAV}} + \sqrt{2h_{Boat}}$$
$$= \sqrt{2 \times 800} + \sqrt{2 \times 18} = 46\ miles = 74.1\ km$$

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8\ m/s}{200\ MHz} = 1.5\ m$$

$$R_{max,Radar} = \sqrt[4]{P_T G^2 (RCS) \frac{\lambda^2}{(4\pi)^3 P_{R,min}}} = \sqrt[4]{1\ \mathrm{kW}(100^2)(40)\frac{(1.5\ m)^2}{(4\pi)^3 * 19fW}} = 69.9km \quad r_{max,LOS} > R_{max,RADAR}$$

Limiting factor/distance

RADAR Warning Receiver (RWR)

- **Threat Detection:** Radar Warning Receivers (RWRs) detect radar emissions from potential threats, providing early warnings of enemy tracking or targeting.
- **Threat Identification:** RWRs analyze radar signals to classify and prioritize threats, distinguishing between friendly and hostile radars.
- **Enhanced Survivability:** RWRs improve situational awareness and geo-location, enabling evasive maneuvers or countermeasures to defend against radar-guided threats.
- **RWRs operate like communications (one-way), therefore *<u>Friis Equation</u>* is applicable**

$$R = \frac{\lambda}{4\pi}\sqrt{\frac{P_T G_T G_R}{P_R}}$$

(Friis Eqn)

F-35 RWR Cueing Synthetic Aperture Radar (SAR)

Example RWR Northrop Grumman

“Who Sees Who First?” Problem

- **Five Step process:**
  1. **Read entire problem and write down givens and unknowns**
  2. **Determine R_{LOS} in km**
  3. **Determine R_{RWR} by using Friis equation (One-Way)**
  4. **Determine R_{RADAR} by using RADAR equation (Round Trip)**
  5. **Compare the three Ranges – Recommend drawing a diagram**
     - When a system can both “see” (LOS) and “hear” (receives enough power), then they can detect
     - First system to “see” and “hear” detects first!

“Who Sees Who First?” Example

- A B-52 with an RCS of 100 m2 is ingressing hostile territory at 30,000’ AGL. The B-52’s RADAR warning receiver (RWR) has a gain of 3 and requires a minimum power of 215 nW to detect enemy RADAR signals. The enemy RADAR is on a 100’ hill and transmits 1kW at 300 MHz with an antenna gain of 150. The enemy RADAR requires a minimum 12fW to detect enemy aircraft. Who sees who first?

"Who Sees Who First?" Example

Solution

- A B-52 with an RCS of 100 m2 is ingressing hostile territory at 30,000' AGL. The B-52's RADAR warning receiver (RWR) has a gain of 3 and requires a minimum power of 215 nW to detect enemy RADAR signals. The enemy RADAR is on a 100' hill and transmits 1kW at 300 MHz with an antenna gain of 150. The enemy RADAR requires a minimum 12fW to detect enemy aircraft. Who sees who first?

$$r_{max,LOS} = \sqrt{2h_{B-52}} + \sqrt{2h_{radar}} = \sqrt{2 \times 30,000} + \sqrt{2 \times 100}$$
$$= 259\ miles = 417.1\ km$$

$$\lambda = \frac{c}{f} = \frac{3 \times\ 10^8\ m/s}{300\ MHz} = 1\ m$$

$$R_{radar} = \sqrt[4]{P_T G^2 RCS \frac{\lambda^2}{(4\pi)^3 P_R}} = \sqrt[4]{\frac{(1000\ W)(150)^2(100\ m^2)(1\ m)^2}{(4\pi)^3(12 \times 10^{-15}\ W)}} = 98.6\ km$$

$$R_{RWR} = \sqrt{\frac{P_T G_T G_R \lambda^2}{(4\pi)^2 P_R}} = \sqrt{\frac{(1000\ W)(150)(3)(1\ m)^2}{(4\pi)^2(215 \times 10^{-9}\ W)}} = 115.1\ km$$

The RWR will detect first at 115.1 km, so the B-52 can avoid the RADAR

Height Bomber (h_{B52})	$30,000\ ft$
RWR Antenna Gain (G_R)	3
RWR Min Power ($P_{R,min}$)	215nW
RCS	100 m^2
Frequency (f)	$300\ MHz$
Height Radar (h_{Radar})	$100\ ft$
Antenna Gain (G_T)	150
Min Receive Power ($P_{R,min}$)	$12f$W
Power Transmitter (P_T)	1 kW

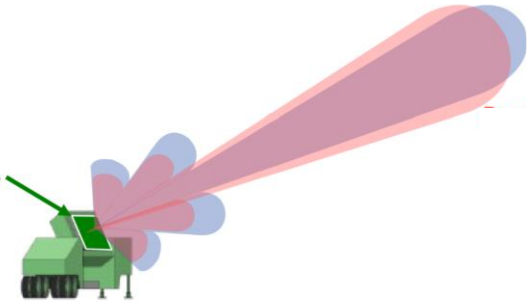
“Who Sees Who First?” Example

Solution

$$r_{max,LOS} = 417.1\ km$$

$$R_{max,RWR} = 115.1\ km$$

$$R_{max,radar} = 98.6\ km$$



Radar Detection Range (98.6 km)

RWR Detection Range (115.1 km)

Line of Sight (LOS) Both Radar and Aircraft (417.1km)

Summary

- **Double the Distance:**
  - **Radio:** $\frac{1}{4}$ **Power Received** $(\frac{1}{R^2})$
  - **Radar:** $\frac{1}{16}$ **Power Received** $(\frac{1}{R^4})$

- **"Who sees who first?" Scenarios. Calculate:**
  - R_{LOS} **in km**
  - R_{RWR} $\ldots Using\ Friis$
  - R_{Radar}