Fundamentals of Time and Frequency in Aerospace and Defense

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The Role of Precise Time and Frequency in Aerospace and Defense

- **Time and Frequency are a critical enabling factors for multiple aerospace and defense applications**
  - Navigation
  - Communications
  - Radar
  - Electronic Warfare Systems
- **An extra dimension of complexity is added in these applications due to dynamic environmental conditions**

Goals of this Tutorial

- **Focus on radar as an aerospace and defense application**
- **2 radar examples will be used to illustrate the importance of the concepts from other tutorials**
- **Radar performance is heavily dependent upon on the local oscillator (LO) at the transmit and receive points**
- **The examples ignore the contribution of other components of the system on things like noise figures for illustration purposes**

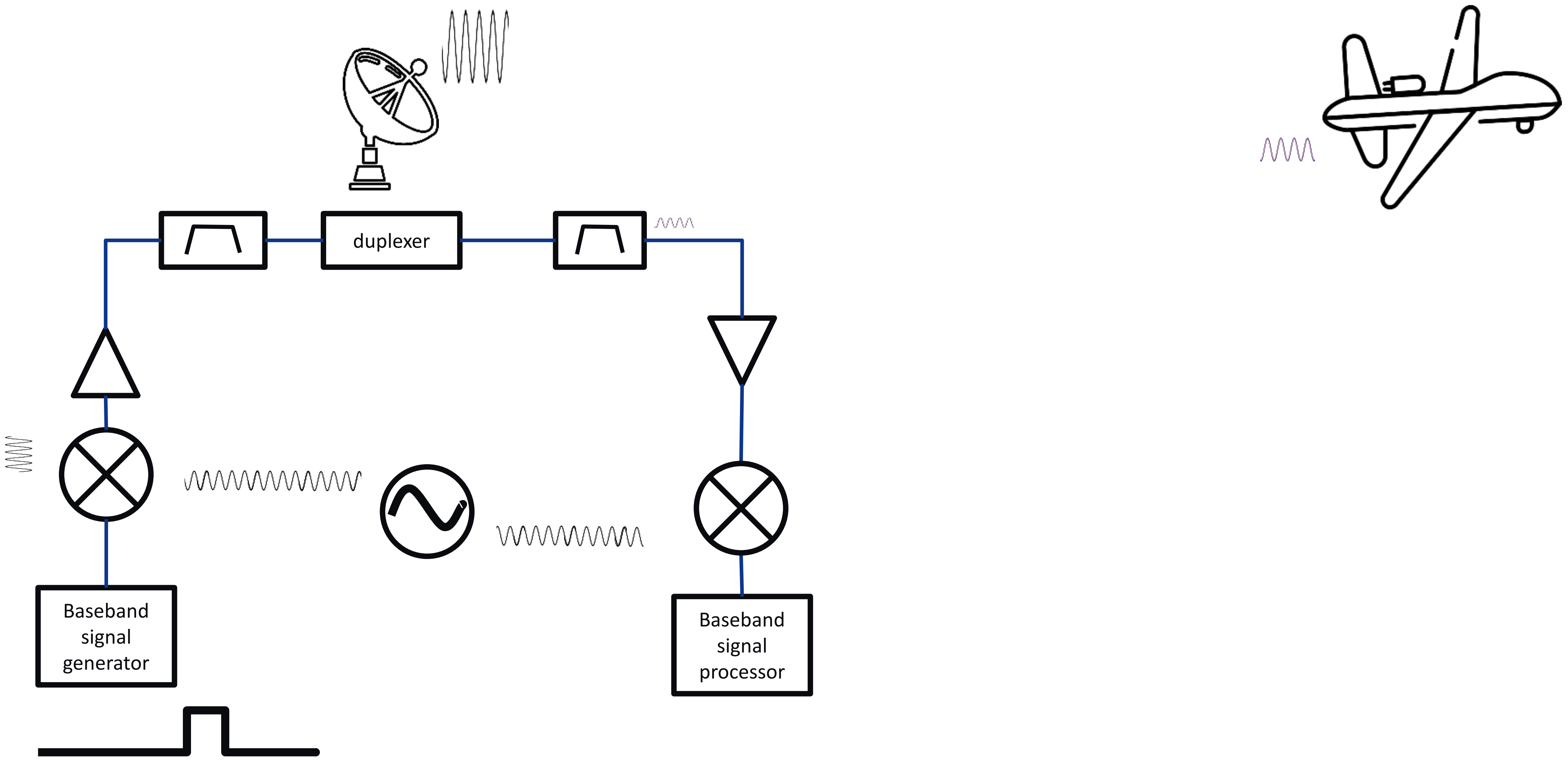
Radar Functions

- **Radar (Radio Detection and Ranging) is a fairly simple concept**
- **At its core it serves three purposes:**
  - Detect Object Presence –
    - Did I get a return signal?
    - Locating people buried in rubble during an earthquake

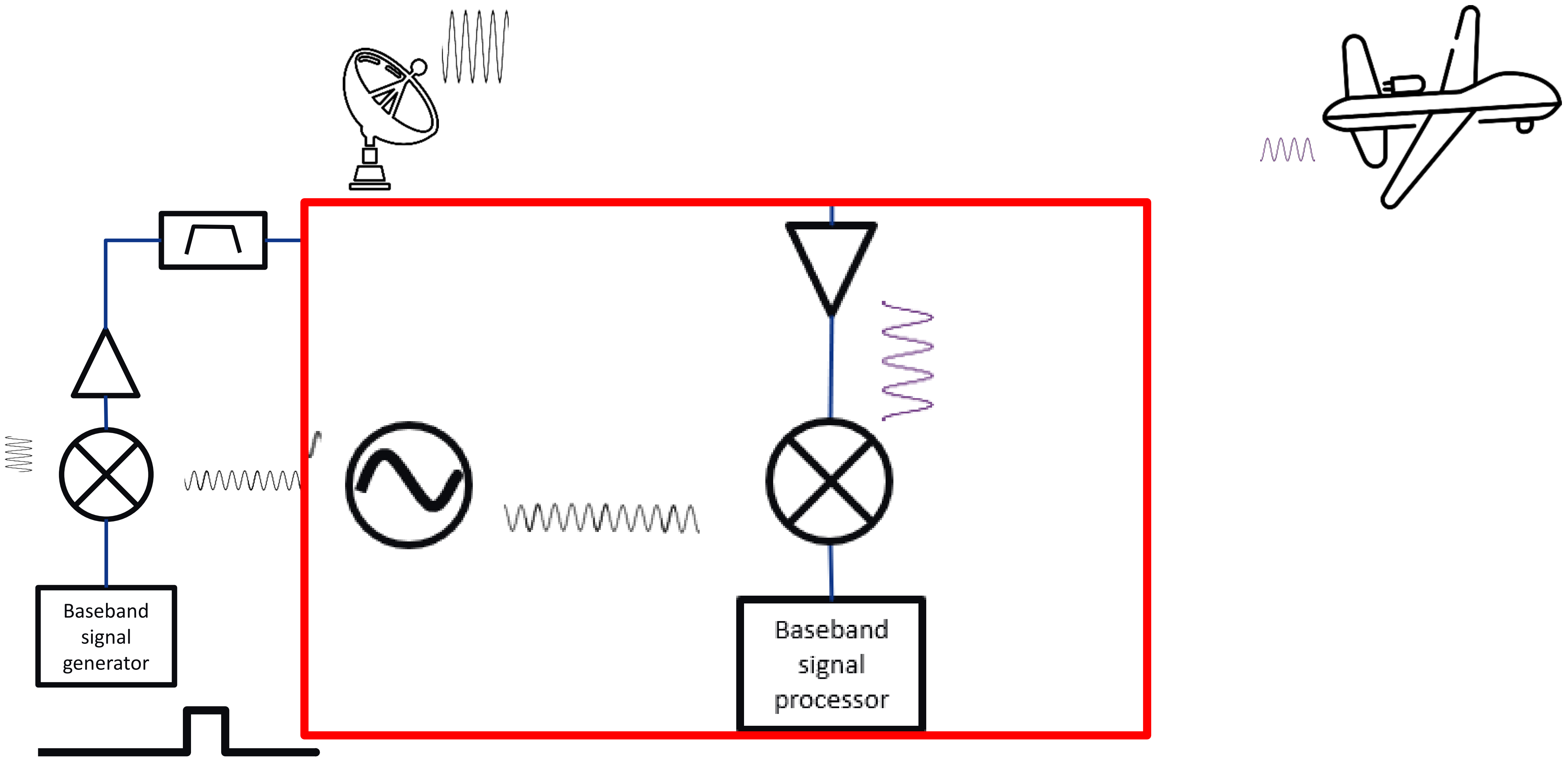
  - Detect Object Distance
    - How long did the signal take to get back to me?
    - Asteroid Tracker

  - Determine Object Speed -
    - Did the signal come back at different frequency?
    - Radar pitch gun

Basic Operation of Pulsed Monostatic Radar



Basic Operation of Pulsed Monostatic Radar



Return Signal Processing and Phase Noise

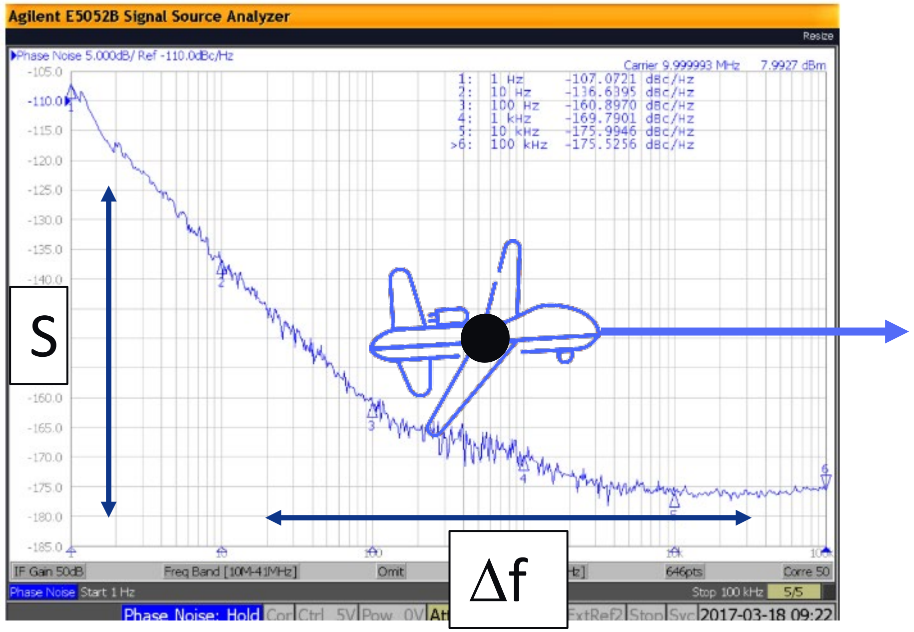
- **Frequency Offset determined by Doppler equation**

$$\Delta f = \frac{2 * V * \cos\theta * f_{tx}}{c}$$

- **Magnitude of Return Signal**

$$S_{dB} = 10 \log \left(\frac{{A_{eff}}^2 {f_{tx}}^2}{c^2 * 4\pi r^4}\right)$$

- $V * cos\theta$ = radial velocity of target
- c=speed of light
- f_{tx} =transmit frequency
- r=distance between radar and target
- A_{eff}=effective area of reflection



Note – other parts of the radar will contribute to S, the magnitude of the return signal must ultimately be at least higher than the phase noise of the LO at the doppler offset when compared in the mixer

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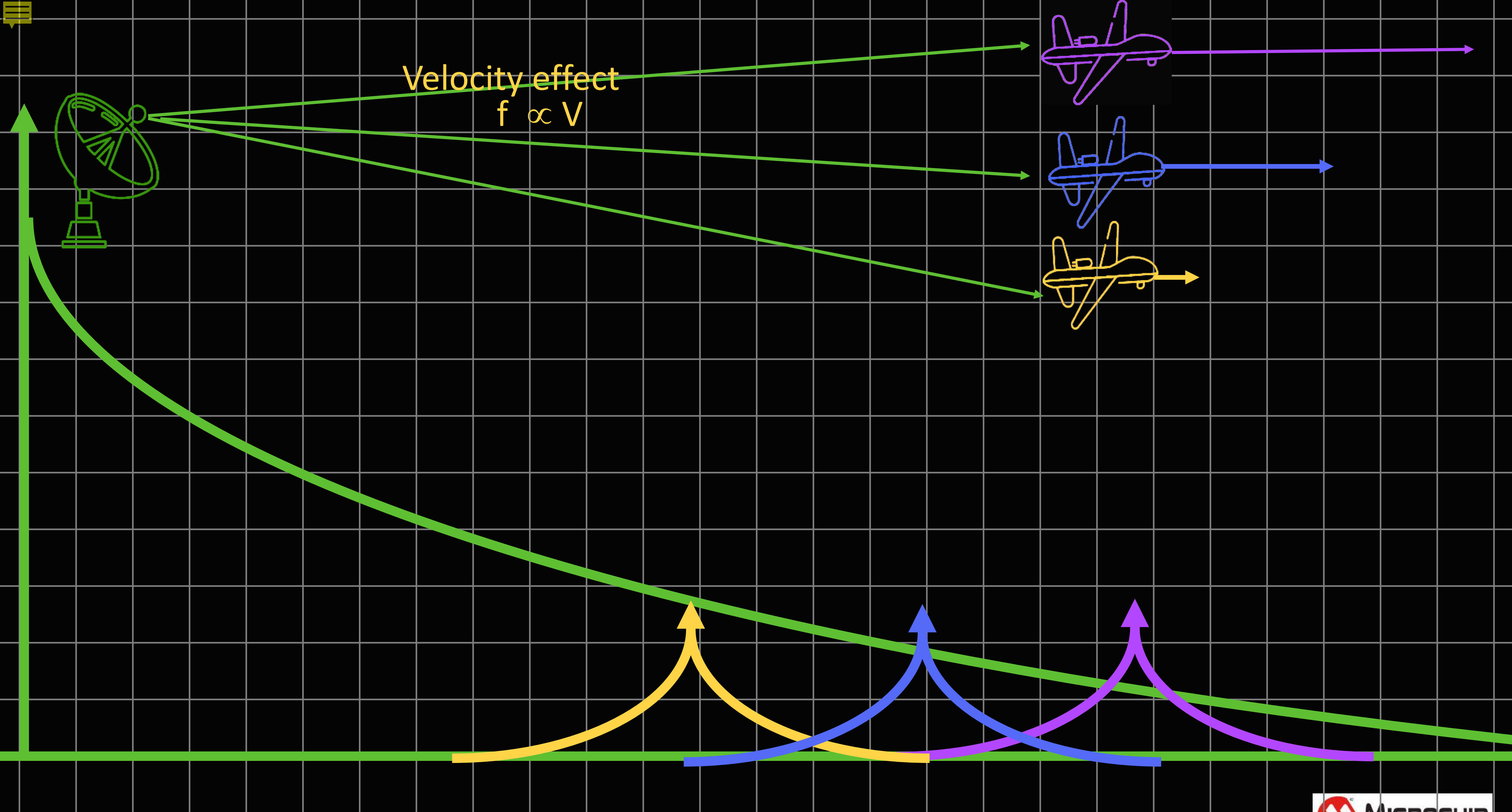
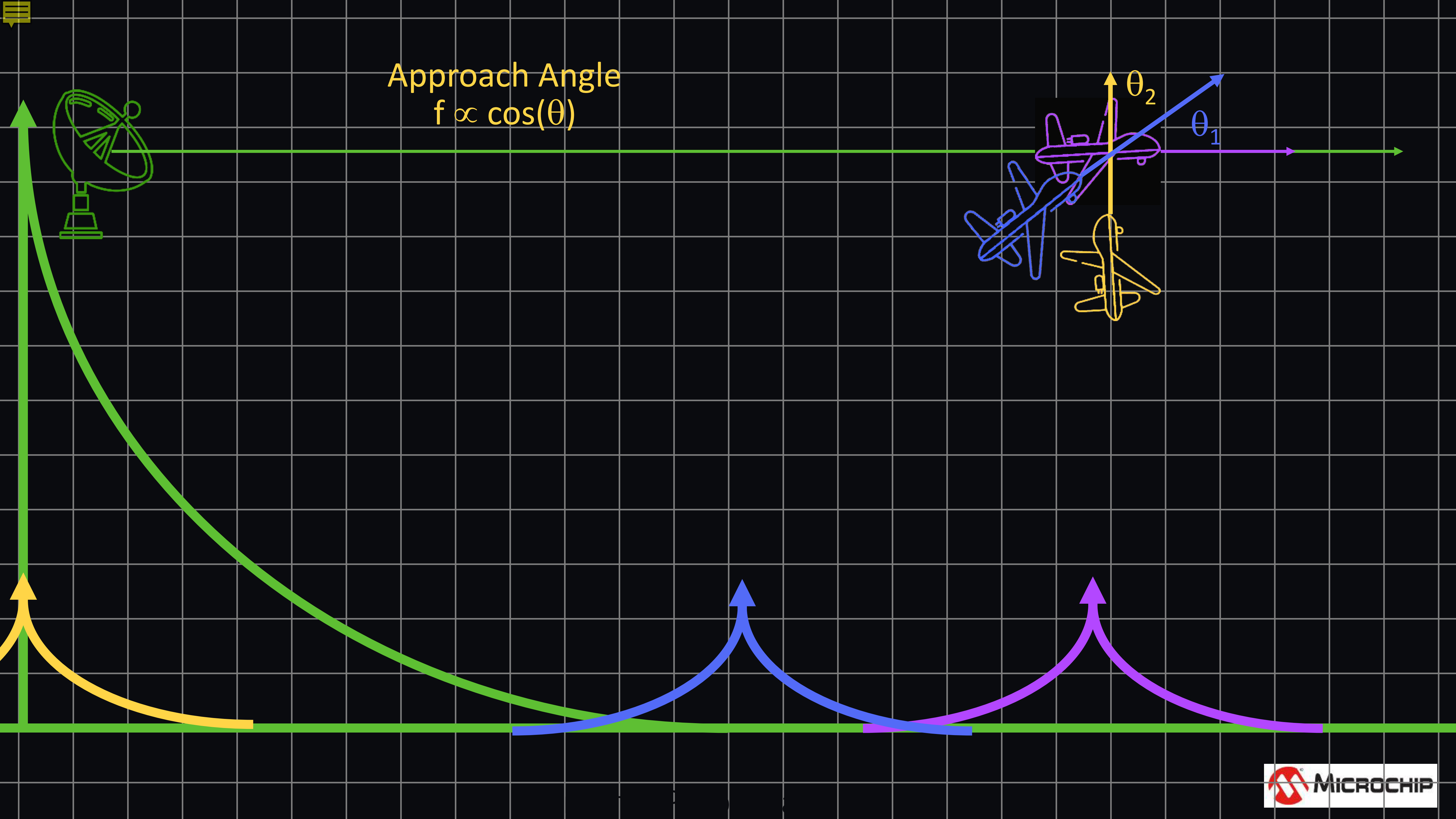

Velocity effect
f ∝ V

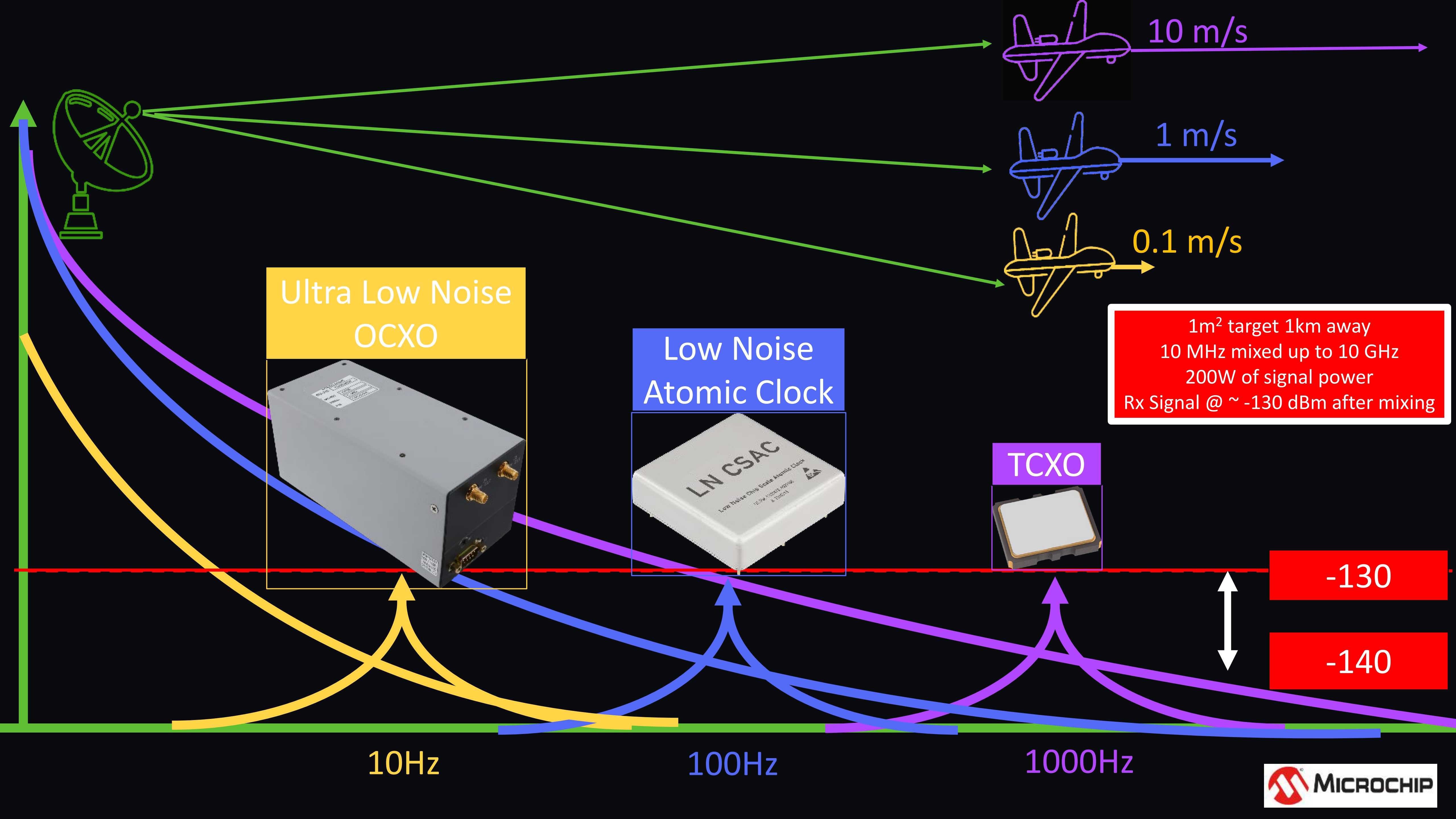

Approach Angle
f ∝ cos(θ)
θ2
θ1


Distance
S ∝ 40 log (r)


Size
$S \propto 20\log(A_{eff})$

Absorption and Deflection

Stealth vehicles intentional absorb or deflect energy. These properties are included in A_{eff}



10 m/s
1 m/s
0.1 m/s
Ultra Low Noise OCXO
Low Noise Atomic Clock
LN CSAC
TCXO
1m² target 1km away
10 MHz mixed up to 10 GHz
200W of signal power
Rx Signal @ ~ -130 dBm after mixing
-130
-140
10Hz
100Hz
1000Hz
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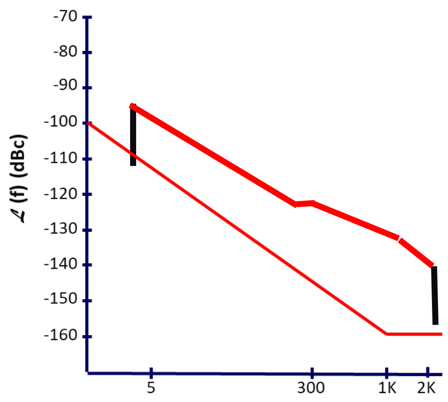
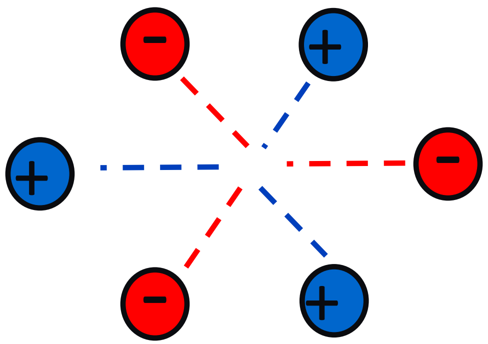
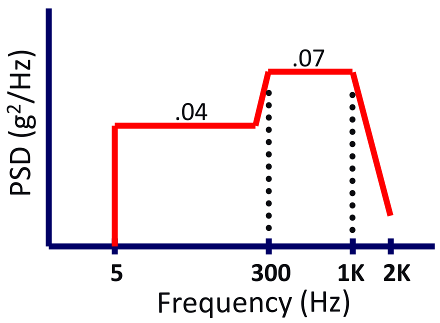
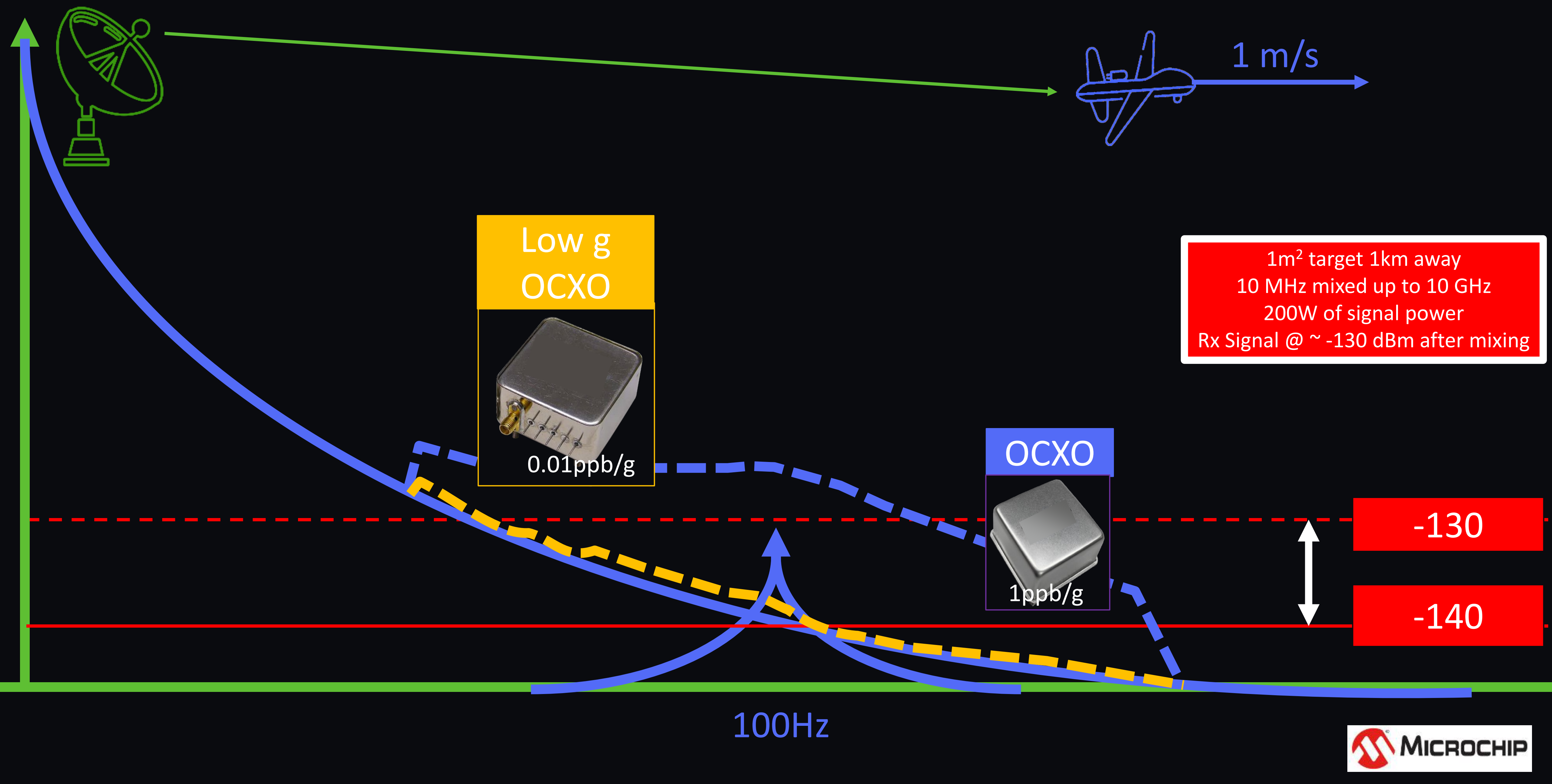
A & D Challenge– g-Sensitivity

- Quartz and MEMS resonators both mechanically vibrate at the resonant electrical frequency (Piezo or Electrostatic)
- That mechanical vibration is subject to modulation from external acceleration and vibration effects
- This additional modulation degrades the phase noise








1 m/s
Low g
OCXO
0.01ppb/g
OCXO
1ppb/g
1m2 target 1km away
10 MHz mixed up to 10 GHz
200W of signal power
Rx Signal @ ~ -130 dBm after mixing
-130
-140
100Hz
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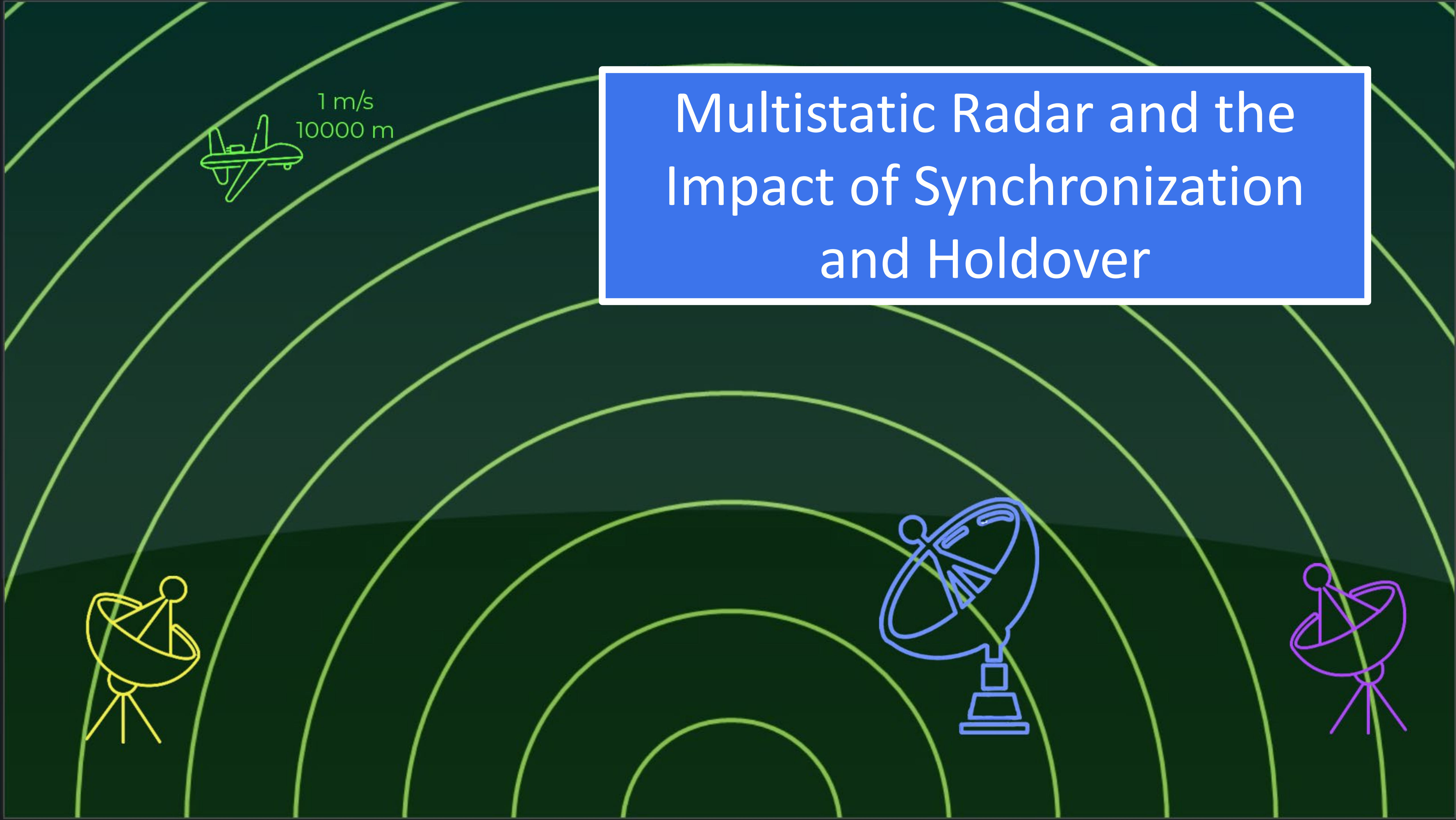
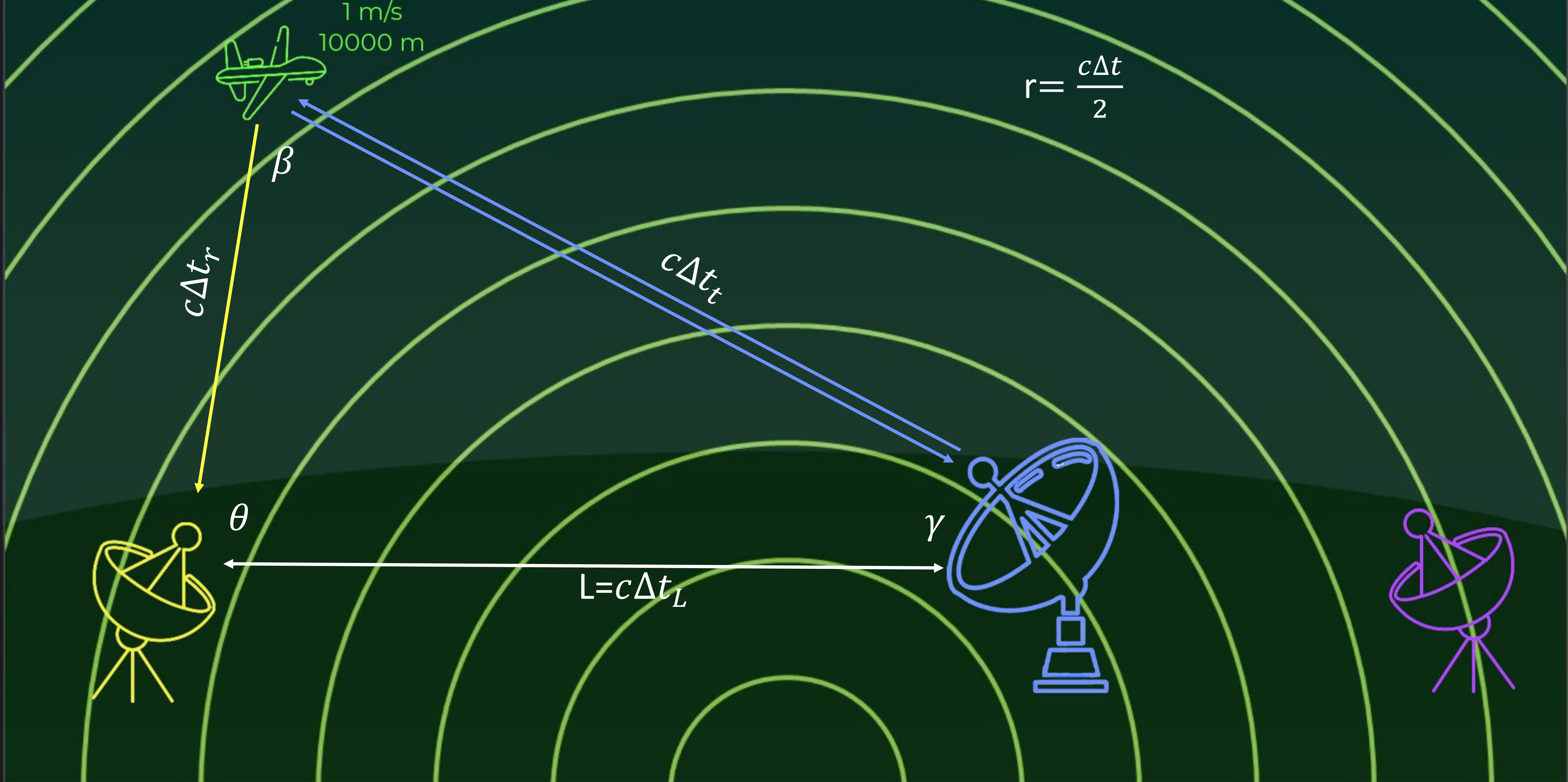
Multistatic Radar and the Impact of Synchronization and Holdover



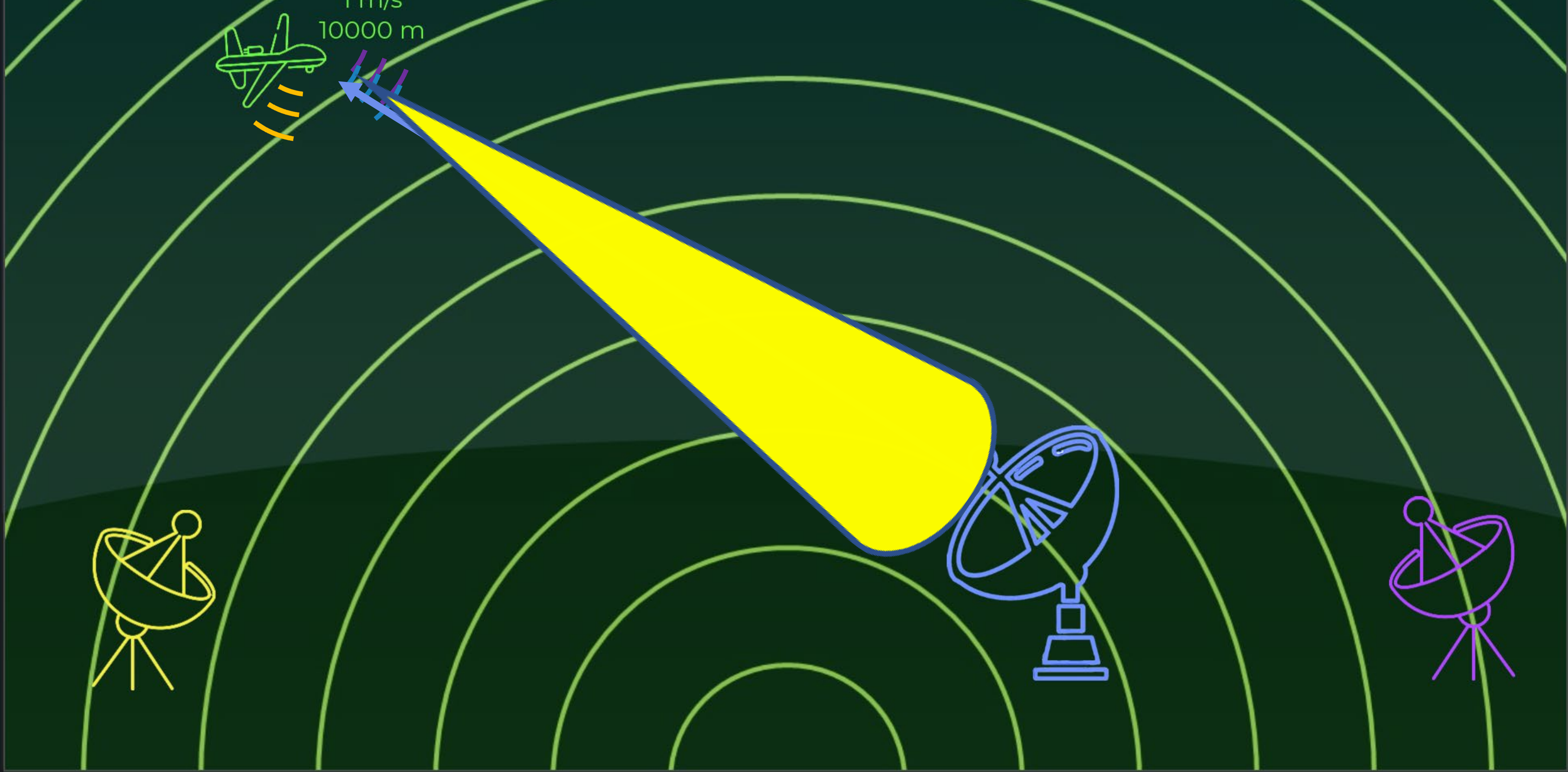
Range

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

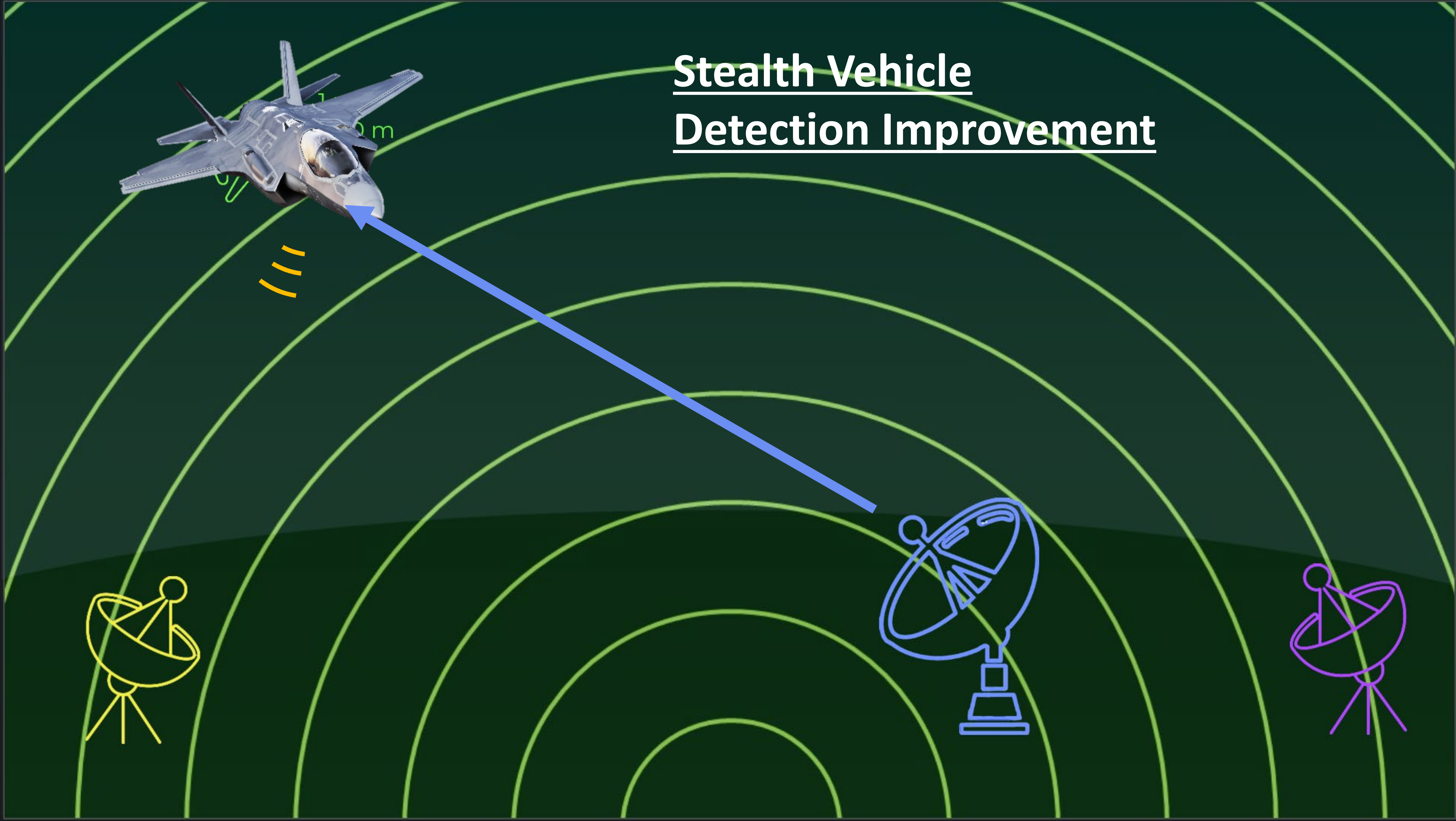


Why use a Multistatic Radar Given the Opportunity for Synchronization Errors?

Jamming Resilience



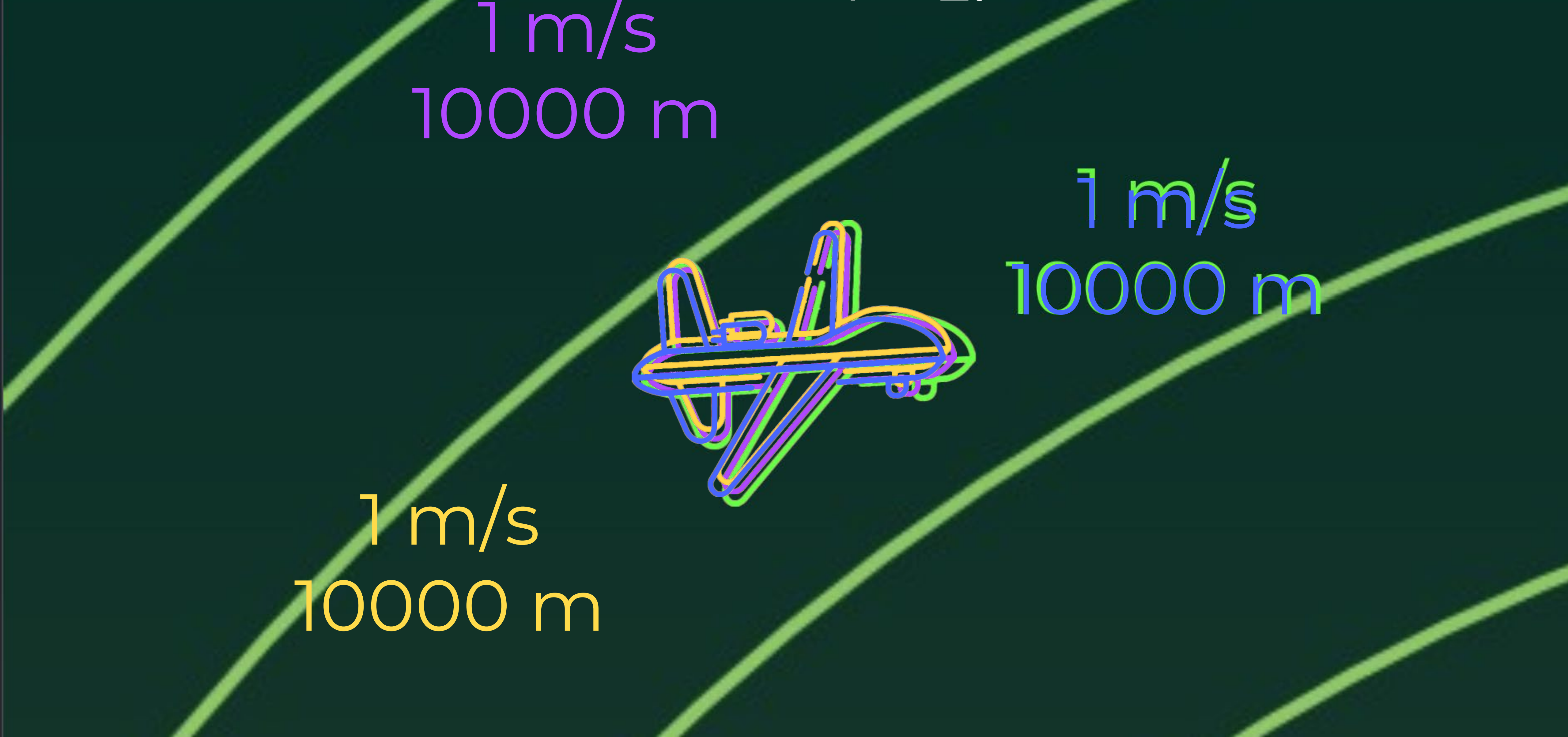
Stealth Vehicle Detection Improvement

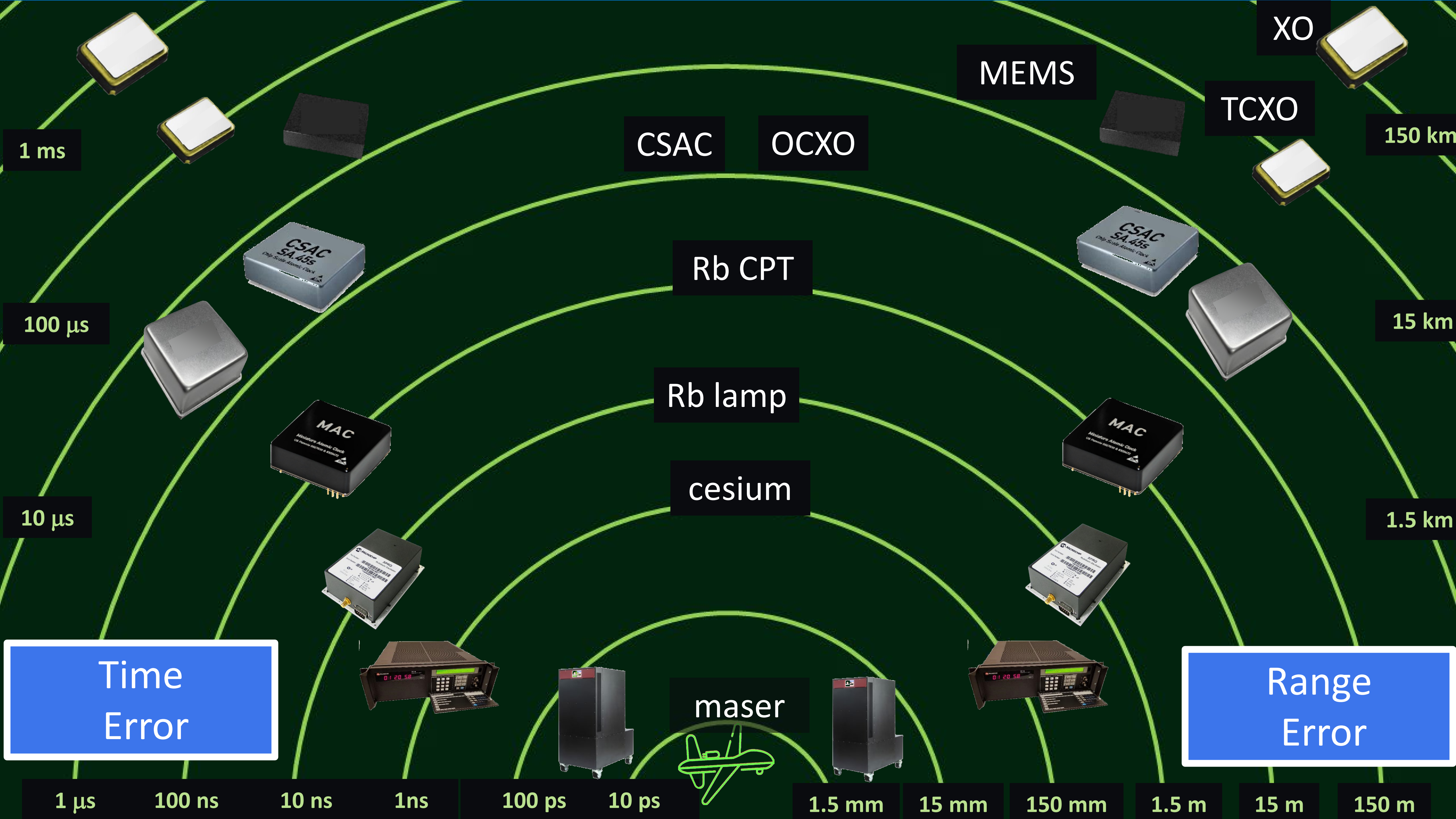


Remote Weapon Launch And Force Protection

Timing Error

$$r \propto \Delta t$$





XO
MEMS
TCXO
CSAC
OCXO
Rb CPT
Rb lamp
cesium
maser
1 ms
100 µs
10 µs
150 km
15 km
1.5 km
Time Error
Range Error
1 µs
100 ns
10 ns
1ns
100 ps
10 ps
1.5 mm
15 mm
150 mm
1.5 m
15 m
150 m

A & D Challenge – Temperature Variation

- Many aerospace and defense applications have extended temperature range when compared to industrial requirements
- In addition to the extended temperature range, the rate of change is much faster


10 °C Change
MEMS
CSAC
OCXO
XO
TCXO
Rb CPT
Rb lamp
cesium
maser
1 ms
100 µs
10 µs
150 km
15 km
1.5 km
CSAC SA.45s
MAC
24 Hour Holdover Error
24 Hour Range Error
1 µs
100 ns
10 ns
1ns
100 ps
10 ps
1.5 mm
15 mm
150 mm
1.5 m
15 m
150 m

Summary

- Phase noise of the LO has a significant impact on the ability of radar to detect a target
- The g-sensitivity of the LO and the vibration profile further impacts the ability of the radar to detect a target during vibration
- Holdover has a significant impact on the range resolution for a multistatic radar
- Temperature profiles can significantly alter the 24-hour holdover capabilities for some LOs

Thanks for Watching