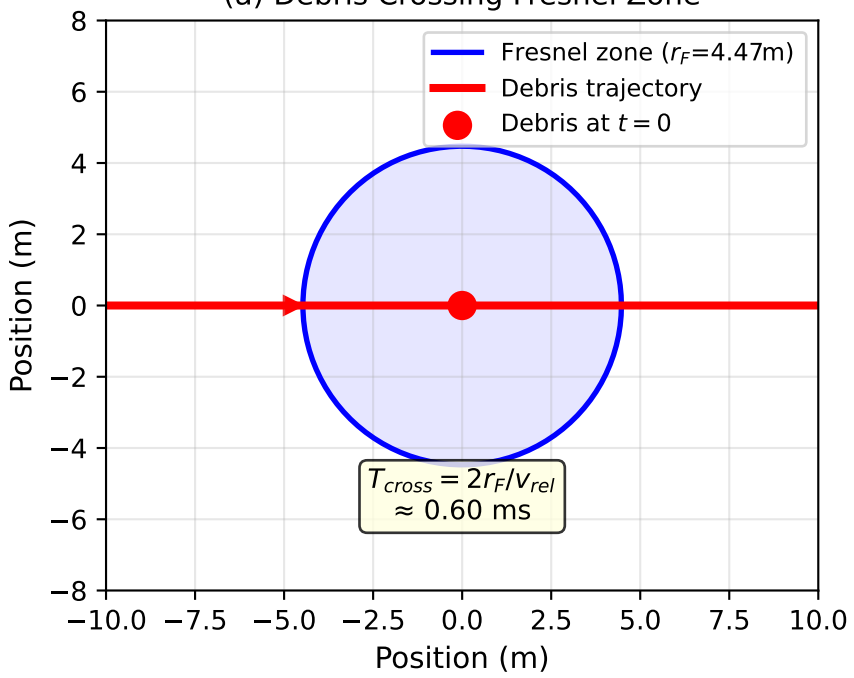
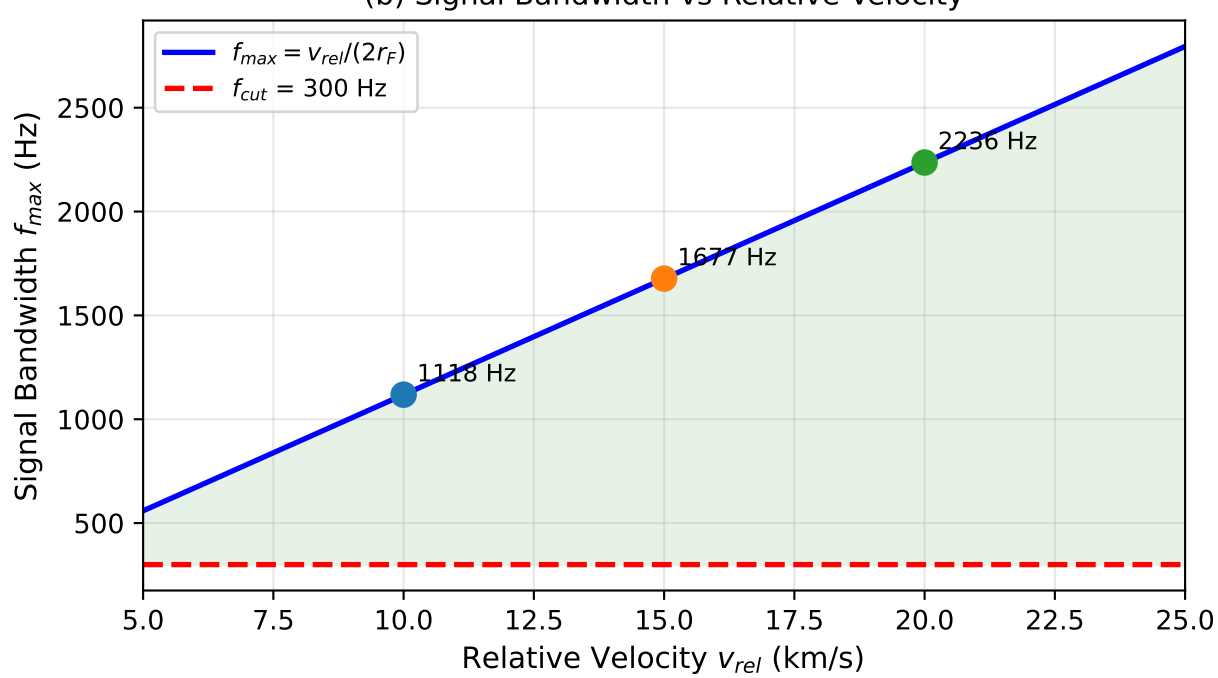
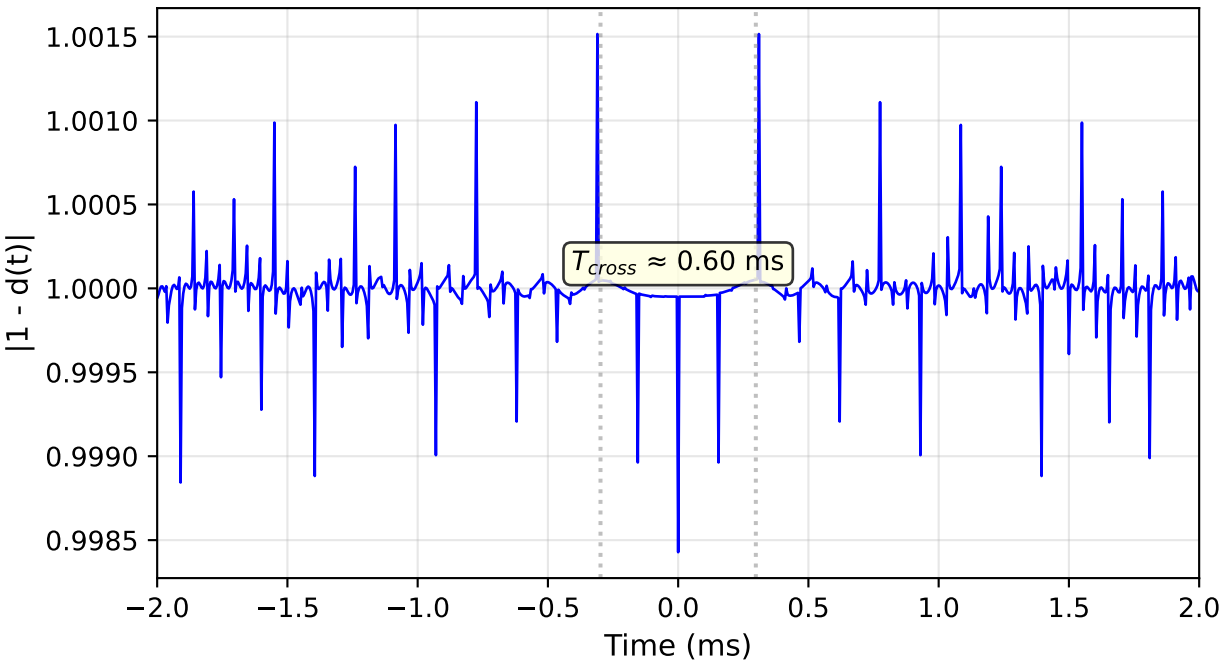
(a) Debris Crossing Fresnel Zone



(b) Signal Bandwidth vs Relative Velocity



(c) Debris Diffraction Modulation (Time Domain)



(d) Theoretical Derivation Summary

SIGNAL BANDWIDTH DERIVATION
{'━'*40}

1. Fresnel Zone Radius
   $r_F = \sqrt{\lambda \cdot L_{eff}}$

   For λ = 1 mm, L_eff = 20 km:
   r_F = √(10⁻³ × 2×10⁴) = 4.47 m

2. Fresnel Crossing Time
   $T_{cross} = \frac{2r_F}{v_{rel}}$

   For v_rel = 15 km/s:
   T_{cross} = 8.94 / 15000 ≈ 0.60 ms

3. Signal Bandwidth Upper Bound
   $f_{max} \approx \frac{1}{T_{cross}} = \frac{v_{rel}}{2r_F}$

   For v_rel = 15 km/s:
   f_{max} ≈ 1677 Hz (NOT 5 kHz!)

4. Survival Space Bounds
   $f_{cut} < f < f_s/2$

   With f_{cut} = 300 Hz:
   300 Hz < f < 100 kHz

KEY CORRECTION:
   □ Old claim: "300 Hz - 5 kHz"
   ✓ Correct: "300 Hz - ~1.7 kHz" (for v=15km/s)