“MITIGATION OF BLIND SPEEDS – DOPPLER EFFECT, AMTI RADAR”

(With textbook references, equations, derivations & diagrams)

INTRODUCTION (Blind Speeds – Doppler Effect, MTI / AMTI Radar)

Blind speeds are a fundamental limitation in Doppler-based radar systems such as MTI (Moving Target Indication) and AMTI (Airborne MTI). They occur when the Doppler frequency shift produced by a moving target coincides with the radar’s Pulse Repetition Frequency (PRF) or its harmonics.

Since MTI radars sample Doppler frequency pulse-to-pulse at the PRF, certain target velocities cause the MTI filter (especially the delay-line canceller) to produce zero output. At these specific velocities—called **blind speeds**—the radar mistakenly suppresses the moving target as if it were stationary clutter.

📖 ***Reference: Skolnik – Introduction to Radar Systems, Chapter 4***

1. DOPPLER EFFECT IN RADAR

When a radar transmits a pulse, a moving target causes a frequency shift in the received echo due to relative motion. This frequency shift is called the **Doppler frequency**.

$$f_d = \frac{2vr}{\lambda}$$

Where:

f_d= Doppler frequency

vr= radial velocity

λ= wavelength

📖 ***Reference → Introduction to Radar Systems – Merrill I. Skolnik, 3rd Edition → p.68-70***

2. BLIND SPEEDS IN RADAR

Blind speeds occur when, for certain target velocities, the Doppler phase shift becomes integer multiples of 2π, causing the MTI canceller to mistakenly cancel the returning echo.

Derivation of Blind Speed Condition (Skolnik)

From the output of a single delay-line canceller:

$$V = 2k\sin(\pi f_d T)\cos(2\pi f_d(t - \frac{T}{2}) - \phi_0)$$

Amplitude term:

$$| H(f_d) | = 2\sin(\pi f_d T)$$

Zero output when:

$$\sin(\pi f_d T) = 0$$

Thus:

$$\pi f_d T = n\pi \Rightarrow f_d = \frac{n}{T} = n f_p$$

Using Doppler formula:

$$f_d = \frac{2v}{\lambda}$$

Blind speed occurs when MTI response = 0; therefore:

$$\boldsymbol{v_n = \frac{n\lambda f_p}{2}}$$

Skolnik states blind speeds are a severe limitation of MTI radars, especially at higher frequencies (S-band, X-band).

📖 ***Reference → Introduction to Radar Systems – Merrill I. Skolnik, 3rd Edition → p.117–118***

3. METHODS TO MITIGATE BLIND SPEEDS (PAGE-WISE)

METHOD–1: OPERATE AT LONG WAVELENGTH (LOW FREQUENCY, LARGE λ)

Skolnik states that "MTI radar must operate at long wavelengths or high PRFs if the first blind speed is to exceed the maximum radial velocity."

$$v_{\text{blind}} = \frac{\lambda f_p}{2}$$

Blind speed ∝ λ

- Increasing wavelength (UHF/L-band) **increases blind speed**, reducing blind zones.

📖 ***Reference → Introduction to Radar Systems – Merrill I. Skolnik, 3rd Edition → p.118***

METHOD–2: USE HIGH PRF (LARGE f_p)

$$v_n = \frac{n\lambda f_p}{2}$$

- Higher PRF pushes blind speeds to larger velocities.
- Drawback: unambiguous range decreases

$$R_u = \frac{c}{2f_p}$$

📖 ***Reference → Introduction to Radar Systems – Merrill I. Skolnik, 3rd Edition → p.117–118***

METHOD–3: MULTIPLE / STAGGERED PRFs

Skolnik states that "Use of more than one PRF reduces the effect of blind speeds and sharpens the low-frequency cutoff."

- Use PRF_1, PRF_2 … such that blind speeds do not coincide.
- Staggered PRF raises effective blind speed to the LCM of PRFs.

Composite blind speed condition

Blind speeds only occur when

$$\frac{n_1}{T_1} = \frac{n_2}{T_2} = \cdots$$

Richard's frequency response

$$\mid H_{2,P}(f) \mid^2 = 4 \sum_{p=0}^{P-1} \sin^2(\pi f T_p)$$

📖 ***Reference → Introduction to Radar Systems – Merrill I. Skolnik, 3rd Edition → p.115–117***

📖 ***Advanced Derivation: Richards — Principles of Modern Radar, Ch.17, p.637***

METHOD–4: WEIGHTED / MULTI-PULSE STAGGERED PRF

- Weighted 3-pulse and 5-pulse cancellers reduce null depth.
- This weakens blind-speed cancellation → improves detection.

📖 ***Reference → Introduction to Radar Systems – Merrill I. Skolnik, 3rd Edition → p.125–126***

METHOD–5: TWO-FREQUENCY MTI (DUAL RF FREQUENCY)

Principle

Transmit two carriers:

$$f_0, f_0 + \Delta f$$

Creates an **effective wavelength**:

$$\lambda_{\text{eff}} = \frac{c}{\Delta f}$$

Blind speed becomes:

$$v_{1,\text{eff}} = \frac{\lambda_{\text{eff}} f_p}{2}$$

Example

If $\Delta f = 0.1 f_0$:

$$\lambda_{\text{eff}} \approx 10\lambda \Rightarrow v_{\text{blind}} \times 10$$

📖 Reference → Introduction to Radar Systems – Merrill I. Skolnik, 3rd Edition → p.148–149

METHOD–6: HIGHER–ORDER CANCELLERS (DOUBLE / TRIPLE)

- Higher-order cancellers **produce broader clutter rejection notches**
- Less sensitive to exact blind-speed locations
- Reduced number of blind-speed nulls

Transfer functions

Two-pulse canceller:

$$H_2(f) = 4\sin^2(\pi f T)$$

Three-pulse canceller:

$$H_3(f) = 8\sin^3(\pi f T)$$

📖 Reference → Introduction to Radar Systems – Merrill I. Skolnik, 3rd Edition → p.109–120

METHOD–7: DIGITAL MTI / MTD (DOPPLER FILTER BANK)

Richards states that “Digital MTI replaces blind-speed nulls with continuous Doppler filters.”

- Digital MTI (MTD) eliminates blind-speed notches.
- Doppler filters replace fixed MTI canceller response with:
    - Continuous filters

- No fixed blind speeds

📖 **Reference → Richards — Principles of Modern Radar, Ch.17, p.637**

5. AMTI RADAR (AIRBORNE MTI RADAR)

AMTI Radar is MTI designed for airborne platforms.
Because aircraft motion causes ground clutter to have Doppler, conventional MTI fails.

📖 **Primary references:**

- **Skolnik – Ch.16, p.145–154**
- **Radar Handbook – Ch.3**
- **Richards – STAP section, p.494–495**

5.1. WHY AMTI IS NEEDED

In airborne radar, the radar platform moves → ground clutter picks up Doppler shift.
Thus **clutter Doppler ≠ 0**:

$$f_c = \frac{2V_p}{\lambda}\cos\theta$$

- MTI clutter notch is no longer at clutter frequency
- Clutter becomes spread
- Blind speeds worsen
- Moving targets get masked

So **conventional MTI fails** → AMTI is required.

📗 ***Reference →Skolnik, Ch.16, p.145***

5.2. PRINCIPLE OF AMTI

- AMTI = MTI **+ platform motion compensation**
- AMTI Signal Model - Total Doppler:

$$f_{total} = f_{target} + f_{platform}$$

- AMTI radar must estimate and subtract $f_{platform}$.

Process:

1. Measure clutter Doppler caused by aircraft motion
2. Shift the MTI filter notch to match clutter
3. Apply MTI without losing moving targets

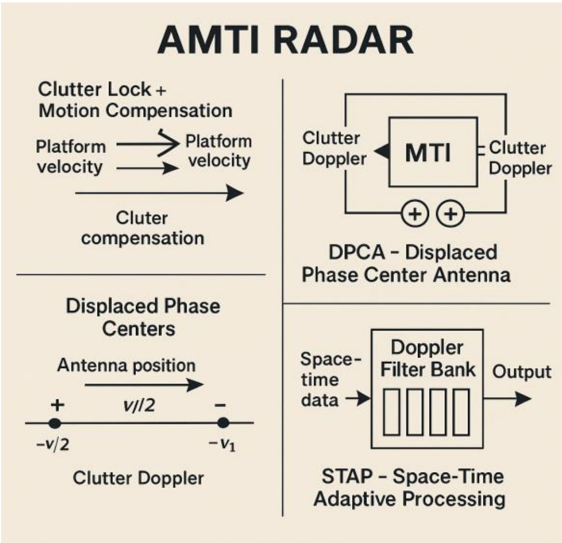
The goal "Cancel platform-motion-induced Doppler before MTI filtering."

📗 **Reference →Skolnik p.145–154**

5.3. AMTI TECHNIQUES (MAIN METHODS)

1. Clutter Lock / Clutter Tracking
2. DPCA (Displaced Phase Center Antenna)
3. ATI (Along-Track Interferometry)
4. Scan-Modulation Compensation
5. Adaptive AMTI (Adaptive Array Processing)
6. STAP (Space-Time Adaptive Processing)

   Optional/Older: TACCAR



5.3.1 Clutter Lock / Clutter Tracking Loop

Radar **estimates mean clutter Doppler** and adjust MTI filter so its notch aligns with clutter.

Function:

- Tracks clutter mean frequency
- Compensates platform velocity
- Prevents MTI blind speeds from shifting

📗 **Reference →*Skolnik p.150–154***

5.3.2 DPCA — Displaced Phase Center Antenna

Two antennas separated by distance **d**.
Clutter phase difference:

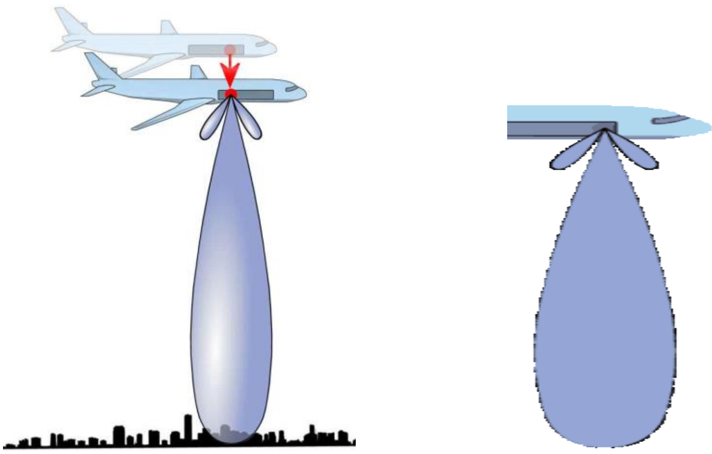
$$\phi = \frac{4\pi d}{\lambda} \sin \theta$$

By subtracting the channels, **platform-motion clutter cancels**.

DPCA benefit:

- Corrects aircraft motion without tracking loops
- Reduces blind speeds
- Improves MTI performance over moving platforms

📚 ***Reference → Skolnik p.147–154***
📚 ***Reference → Radar Handbook Ch.3, p.3.10***



5.3.3 STAP — Space-Time Adaptive Processing

2D filtering using:

- Multiple antenna elements (space)
- Multiple pulses (time)

STAP output:

$$y = w^H x$$

Optimum weights:

$$w = R^{-1} s$$

Capabilities:

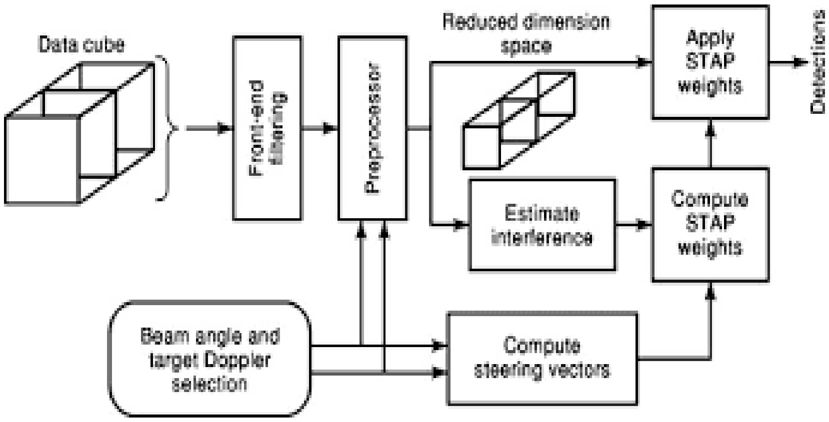
- Cancels clutter ridge

- Cancels platform motion Doppler
- Eliminates blind speeds
- Improves detection in strong clutter

STAP is **the most advanced AMTI method**.

📓 ***Reference → Skolnik Fig.16.23, p.494–495***
📓 ***Reference → Radar Handbook p.16.23***

📓 ***Reference → Richards – Principles of Modern Radar (STAP Chapter)***



5.3.4 ATI (Along-Track Interferometry)

ATI is a form of DPCA that uses phase differences between displaced antennas to detect target motion and reject clutter.
Unlike simple DPCA subtraction, ATI uses interferometric phase.

📓 ***Reference → Radar Handbook, Ch.3 (Airborne MTI Section)***

5.3.4 Scan-Modulation Compensation

When the aircraft scans in azimuth, clutter Doppler changes.
Scan-modulation compensation removes this Doppler variation to maintain correct clutter suppression.

📓 ***Reference → Skolnik, p.153***

5.3.5 Adaptive AMTI (Adaptive Array Processing)

Adaptive AMTI uses adjustable antenna weights to minimize clutter leakage.
This method compensates simultaneously for:

- Platform motion
- Scan modulation
- Sidelobe clutter

This is the predecessor to STAP.

📚***Reference → Skolnik, p.154***

5.3.6 TACCAR (Time-Averaged Coherent Clutter Airborne Radar)

Uses long-term averaging to remove platform-motion Doppler.

Used in older AMTI systems as a simpler alternative to STAP.

📚***Reference → Radar Handbook, 3rd Ed., Ch.16, pp.16.23–16.25***

6. CONCLUSION

Blind speeds arise when the target Doppler frequency coincides with MTI canceller nulls, causing moving targets to be suppressed along with clutter. Several mitigation methods—such as high PRF, long wavelength, multiple PRFs, higher-order cancellers, dual-frequency MTI, and digital MTI—significantly reduce blind-speed effects.

In airborne platforms, platform-induced Doppler and clutter spreading prevent ordinary MTI from functioning correctly. AMTI techniques such as Clutter Lock, DPCA, ATI, Adaptive AMTI, and STAP provide robust motion compensation and clutter suppression. STAP, being a fully adaptive space–time method, is the most advanced and effective approach for modern airborne surveillance radars.