Introduction to Radar Systems

Clutter Rejection

MTI and Pulse Doppler Processing

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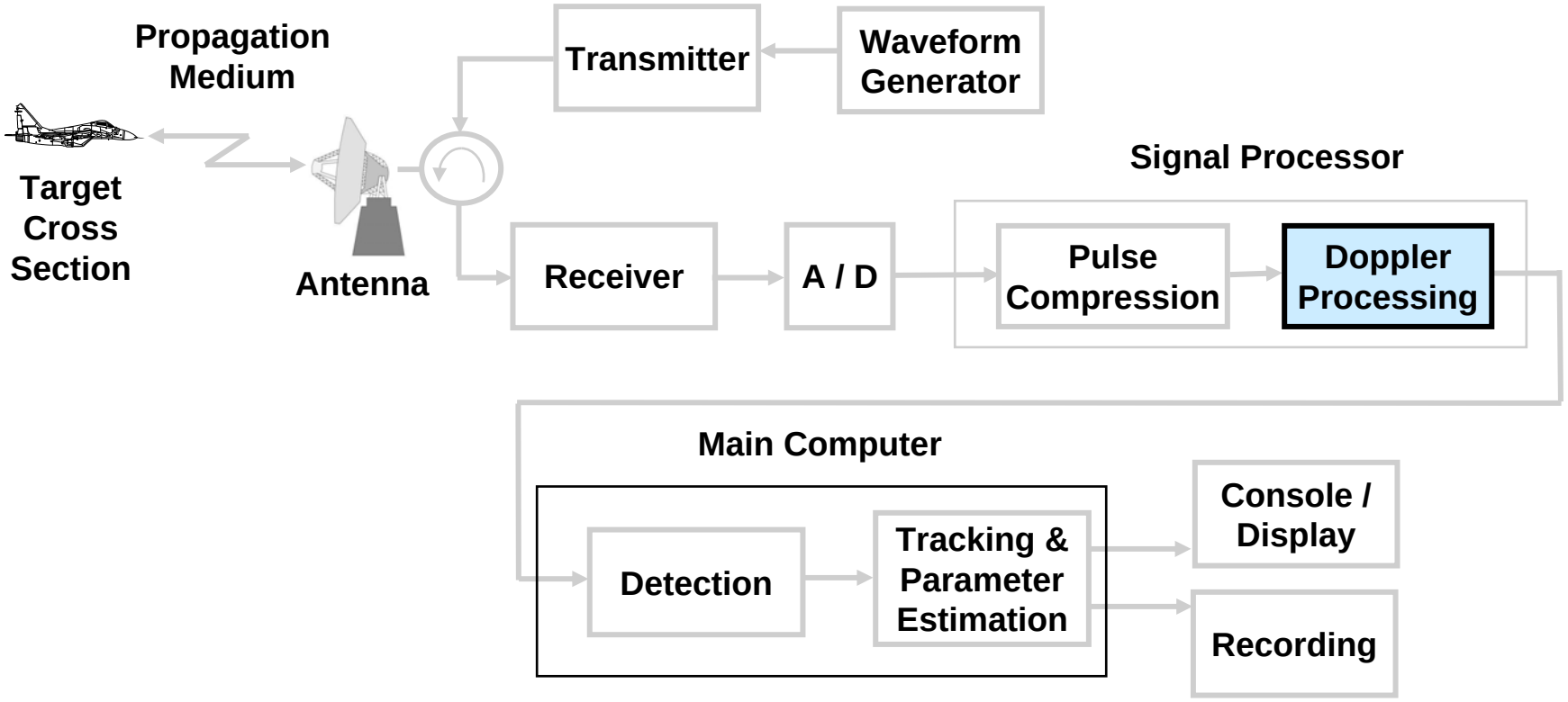
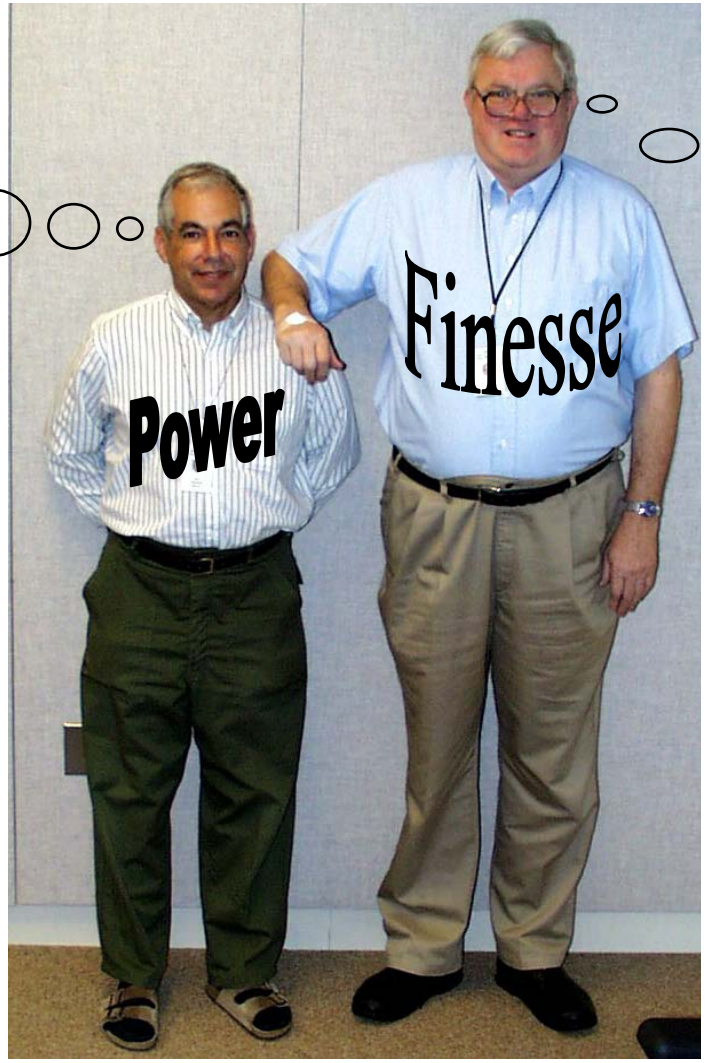
MTI and Doppler Processing



How to Handle Noise and Clutter

How to Handle Noise and Clutter

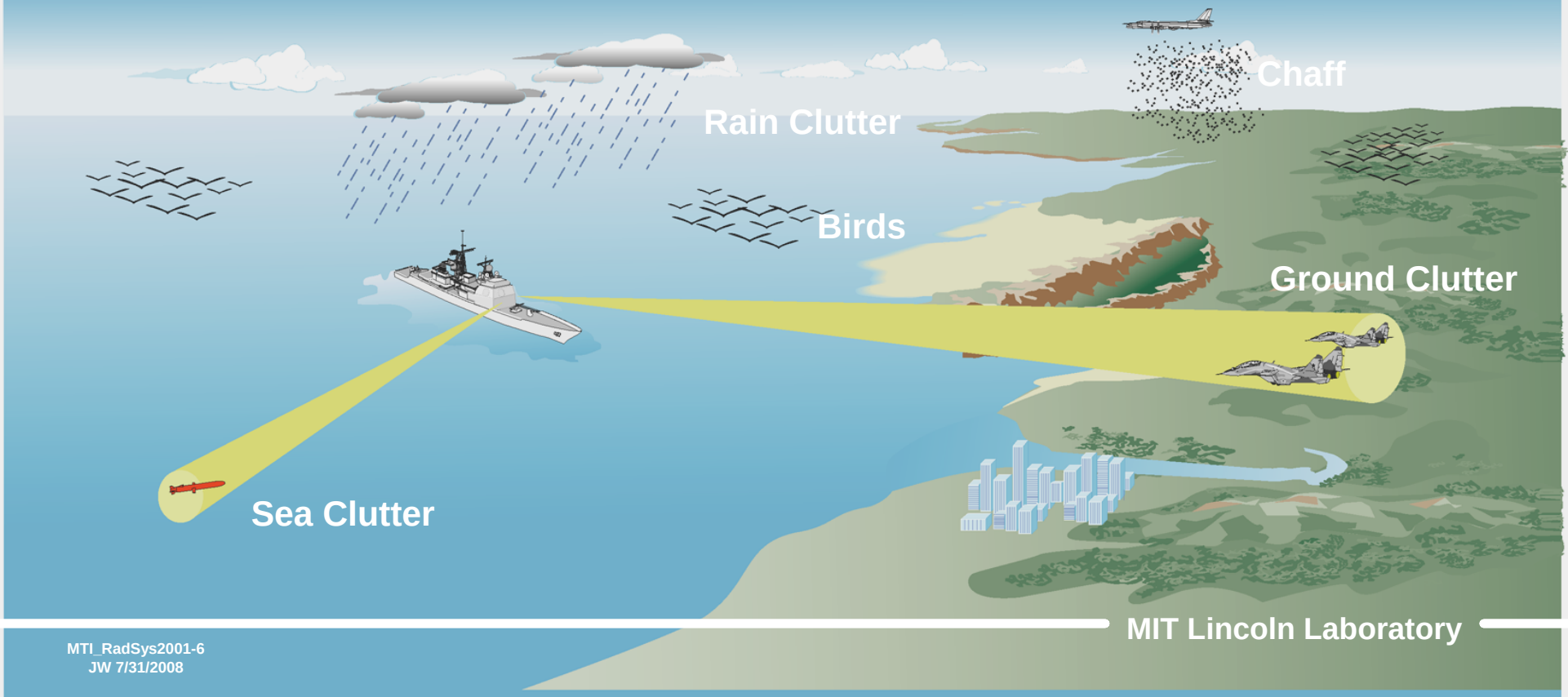
If he doesn't take his arm off my shoulder I'm going to hide his stash of Hershey Bars !!



Why does Steve always talk me into doing ridiculous stunts like this ?

Naval Air Defense Scenario

- Moving Target Indicator (MTI) and Pulse-Doppler (PD) processing use Doppler to reject clutter and enhance detection of moving targets
- Smaller targets require more clutter suppression



Outline

- Introduction
- Moving Target Indicator (MTI) Techniques
- Pulse Doppler Processing Techniques
- Summary

Terminology

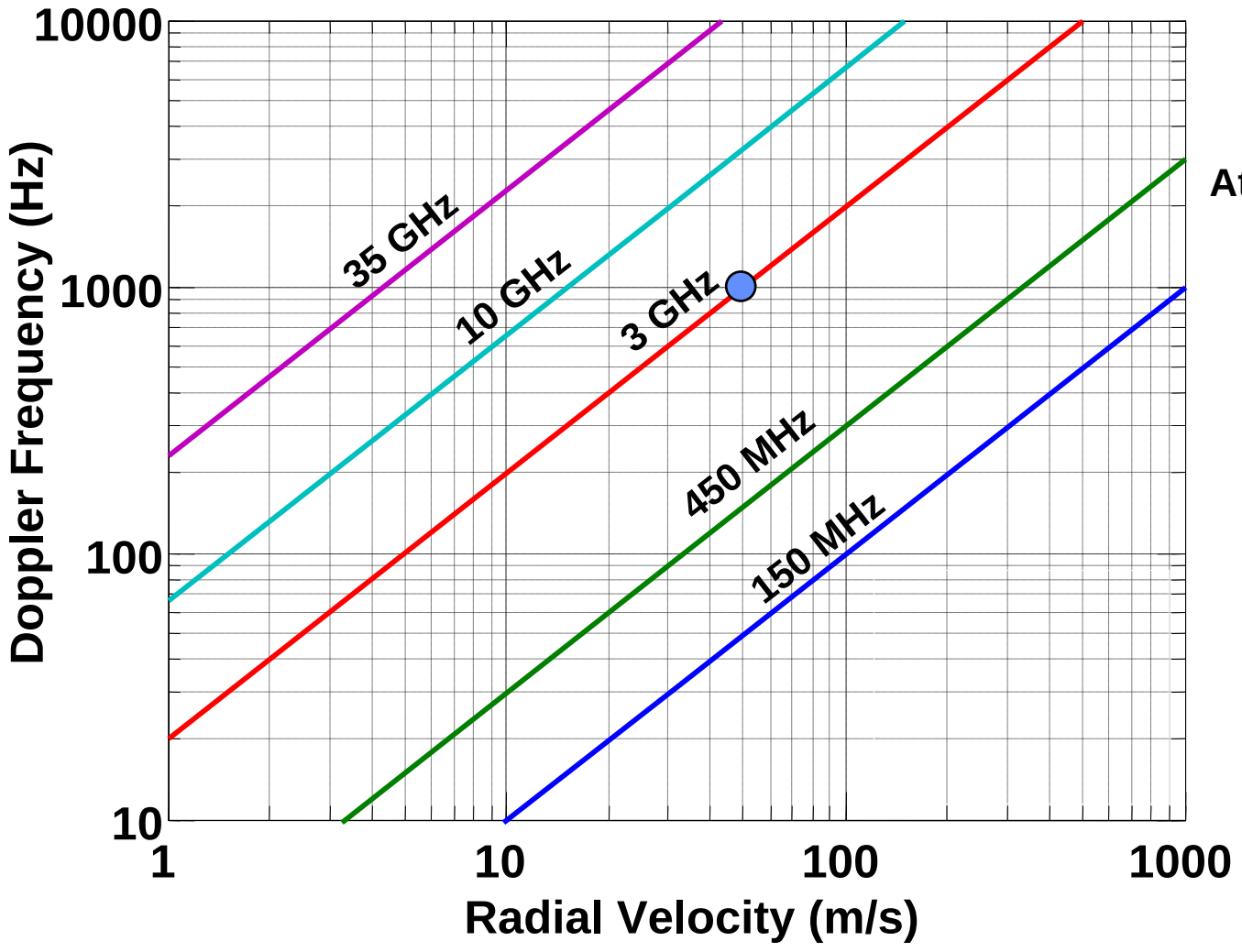
Moving Target Indicator (MTI) Techniques

- Just separate moving targets from clutter
- Use short waveforms (two or three pulses)
- Do not provide target velocity estimation

Pulsed Doppler (PD) Techniques

- Separate targets into different velocity regimes in addition to canceling clutter
- Provide good estimates of target velocity
- Use long waveforms -- (many pulses, tens to thousands of pulses)

Doppler Frequency



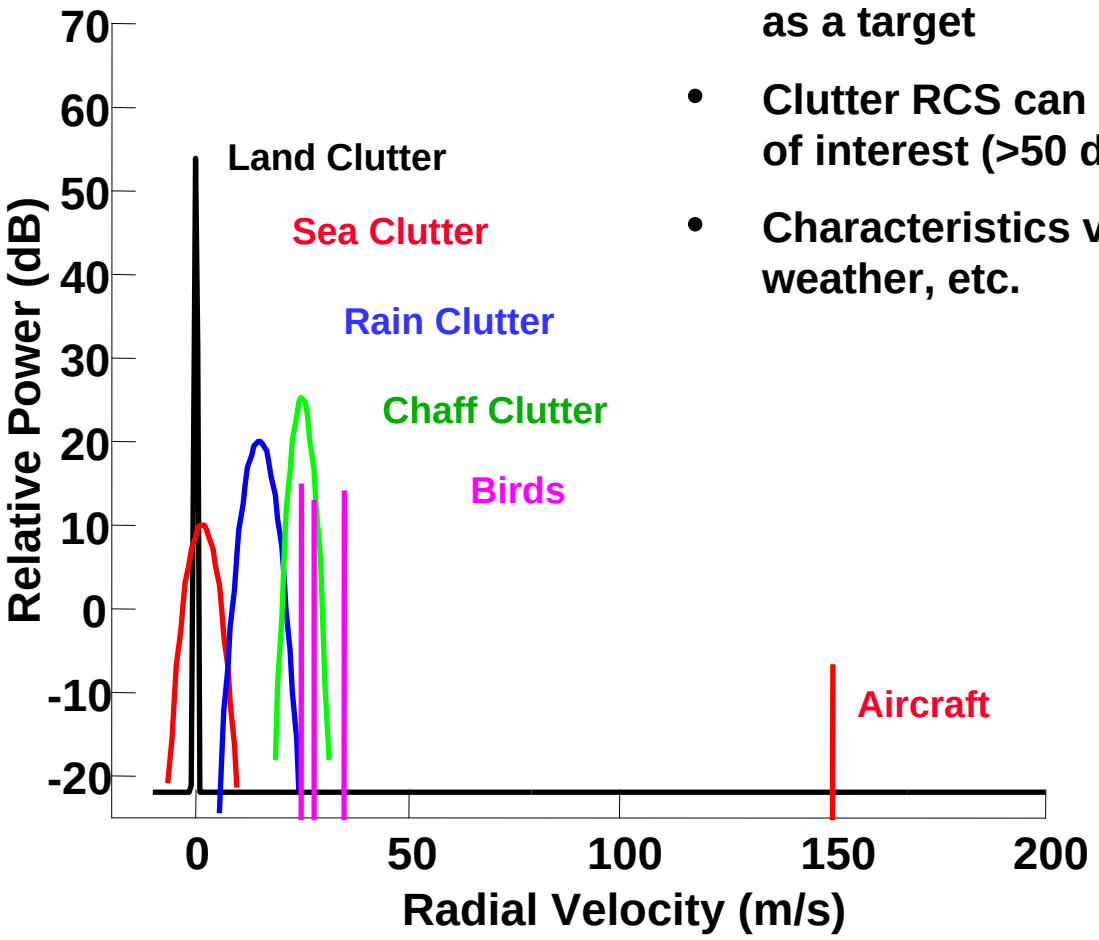
At S-Band (2800 MHz)

f_d ~ 1 kHz / 40 m/s

Doppler Frequency

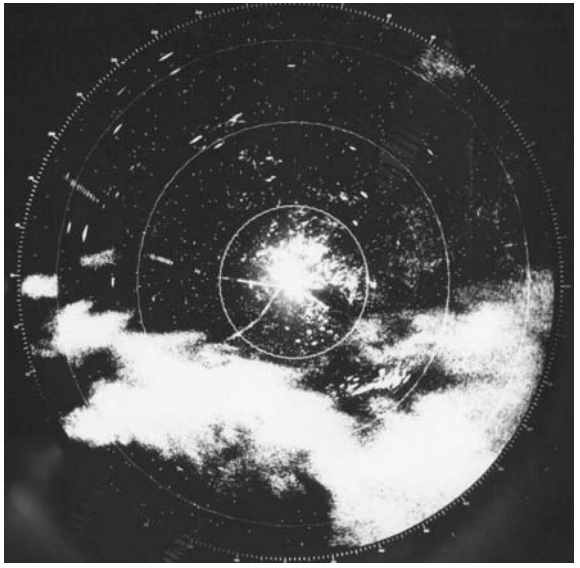
$$f_d = \frac{2V}{\lambda}$$

Example Clutter Spectra

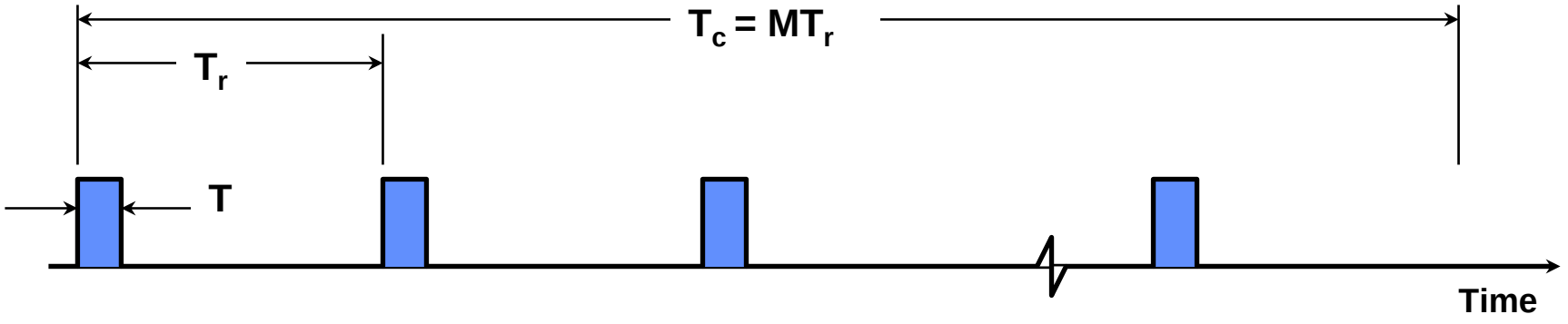


- Clutter comes from same range/angle cell as a target
- Clutter RCS can be much larger than targets of interest (>50 dB)
- Characteristics vary with terrain (land/sea), weather, etc.

PPI Display of Heavy Rain



MTI and Pulse Doppler Waveforms

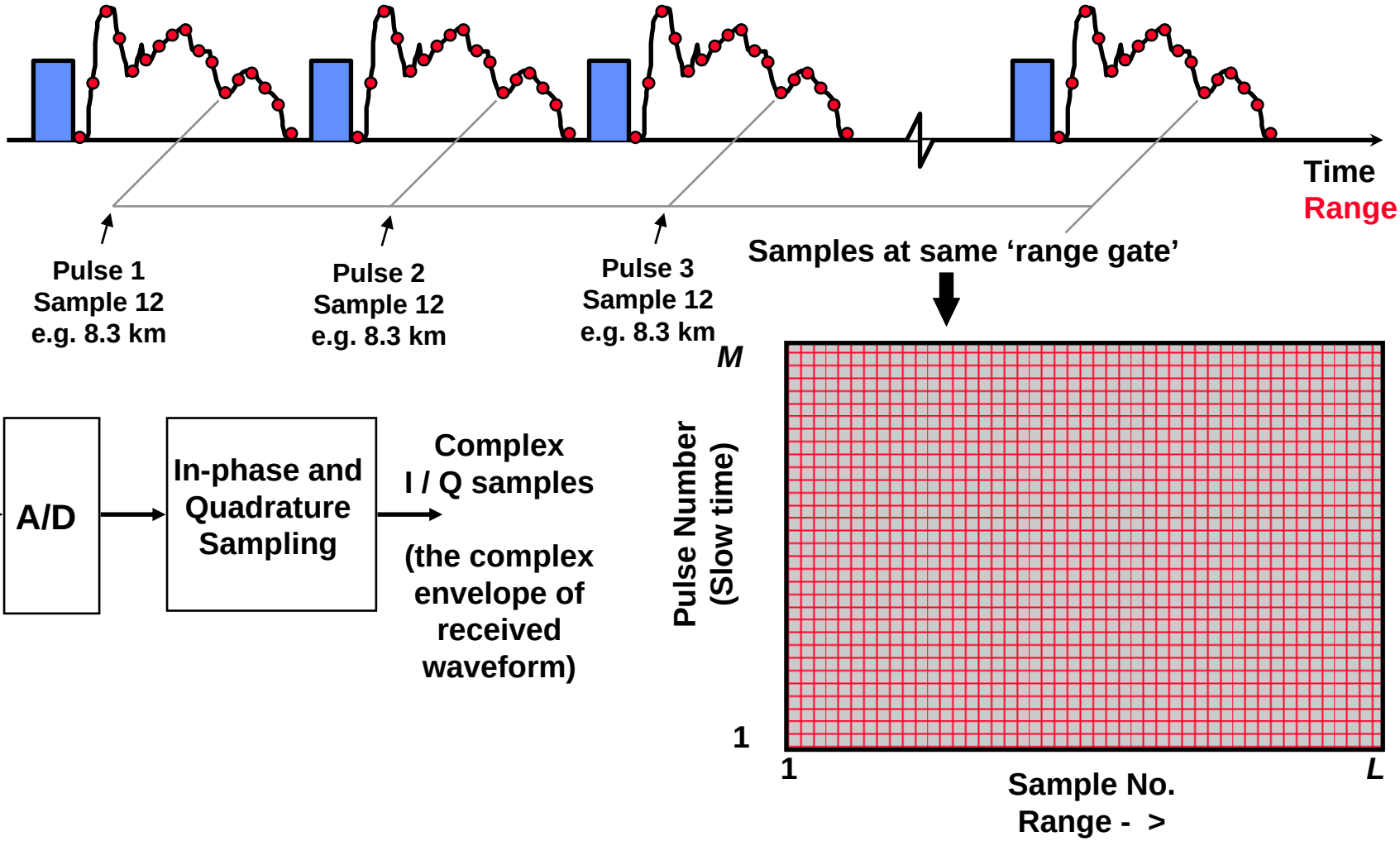


T	=	Pulse length
B	= 1/T	Bandwidth
T_r	=	Pulse repetition interval (PRI)
f_r	= $1/T_r$	Pulse repetition frequency (PRF)
δ	= T/T_r	Duty Factor
T_c	= MT_r	Coherent processing interval (CPI)
M	=	Number of pulses in the CPI

M = 2, 3, or sometimes 4 for MTI

M usually much greater for Pulse Doppler

Data Collection for Doppler Processing



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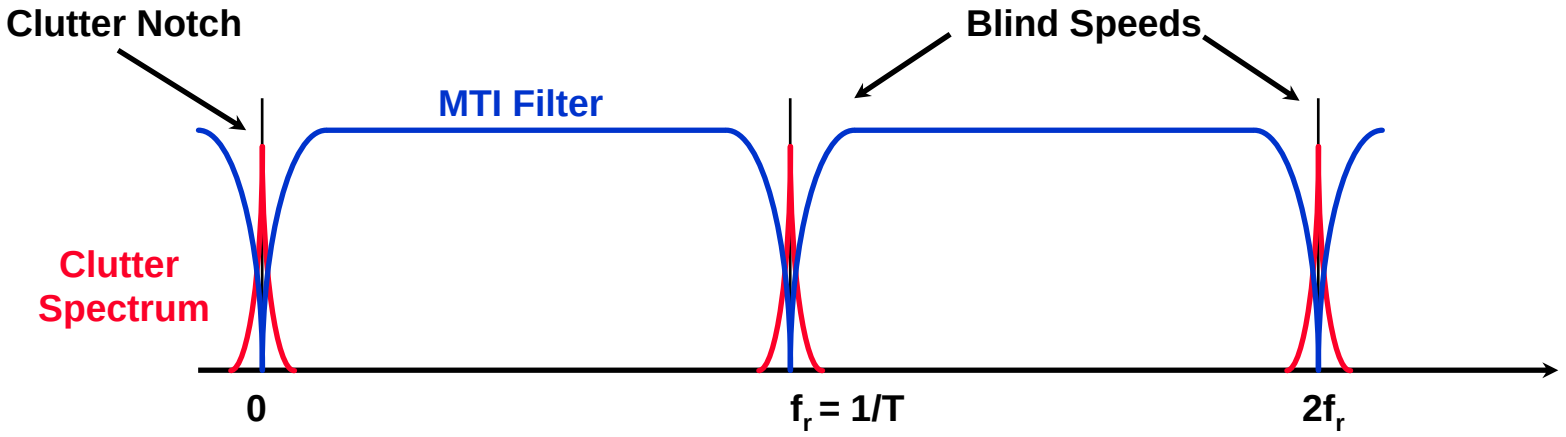
Moving Target Indicator (MTI) Processing

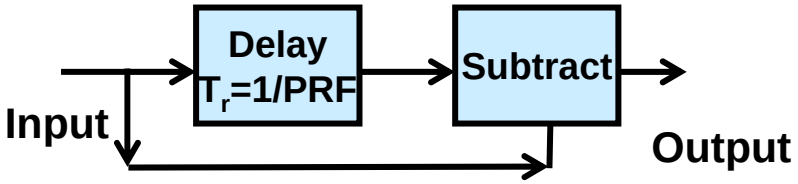
- Notch out Doppler spectrum occupied by clutter
- Provide broad Doppler passband everywhere else
- Blind speeds occur at multiples of the pulse repetition frequency
  - When sample frequency (PRF) equals a multiple of the Doppler frequency



Two Pulse MTI Canceller

- **Fixed Clutter echoes**
  - **If one pulse is subtracted from the previous pulse, fixed clutter echoes will cancel and will not be detected**
- **Moving targets**
  - **Moving targets change in amplitude from one pulse to the next because of their Doppler frequency shift.**
  - **If one pulse is subtracted from the other, the result will be an uncancelled residue**

Block Diagram



$$V_{output} = V_{i+1} - V_i$$

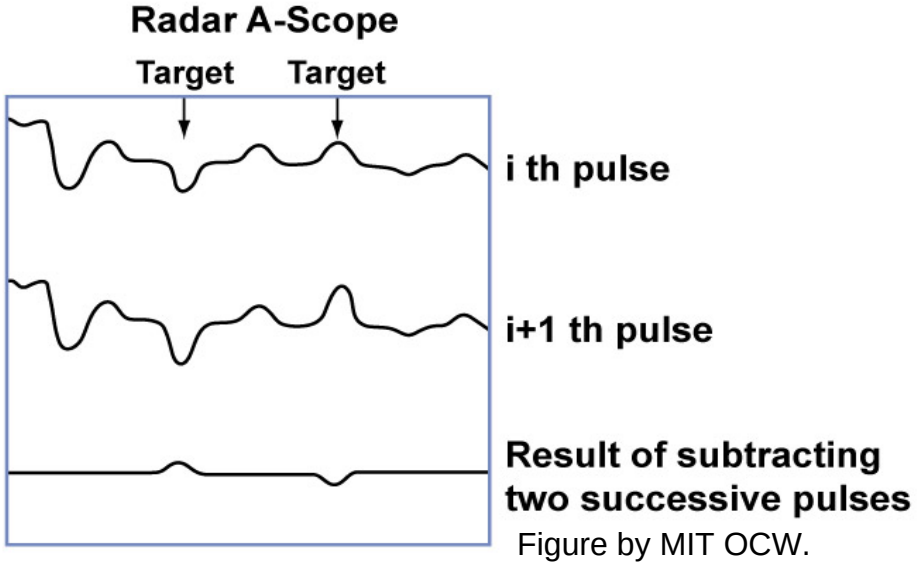
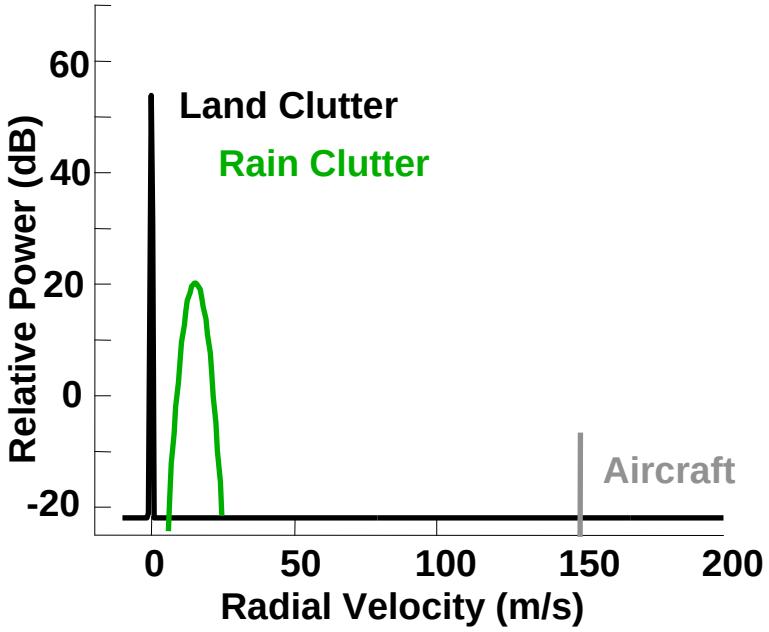


Figure by MIT OCW.

MTI Improvement Factor

- S_{in} and C_{in} - Input target and clutter power per pulse
- $S_{out}(f_d)$ and $C_{out}(f_d)$ – Output target and clutter power from processor at Doppler frequency, f_d
- MTI Improvement Factor = $I(f_d) = \left. \dfrac{(\text{Signal / Clutter})_{out}}{(\text{Signal / Clutter})_{in}} \right|_{f_d}$



MTI Improvement Factor

$$I(f_d) = \left. \frac{C_{in}}{C_{out}} \times \frac{S_{out}}{S_{in}} \right|_{f_d}$$

Clutter Attenuation

Signal Gain

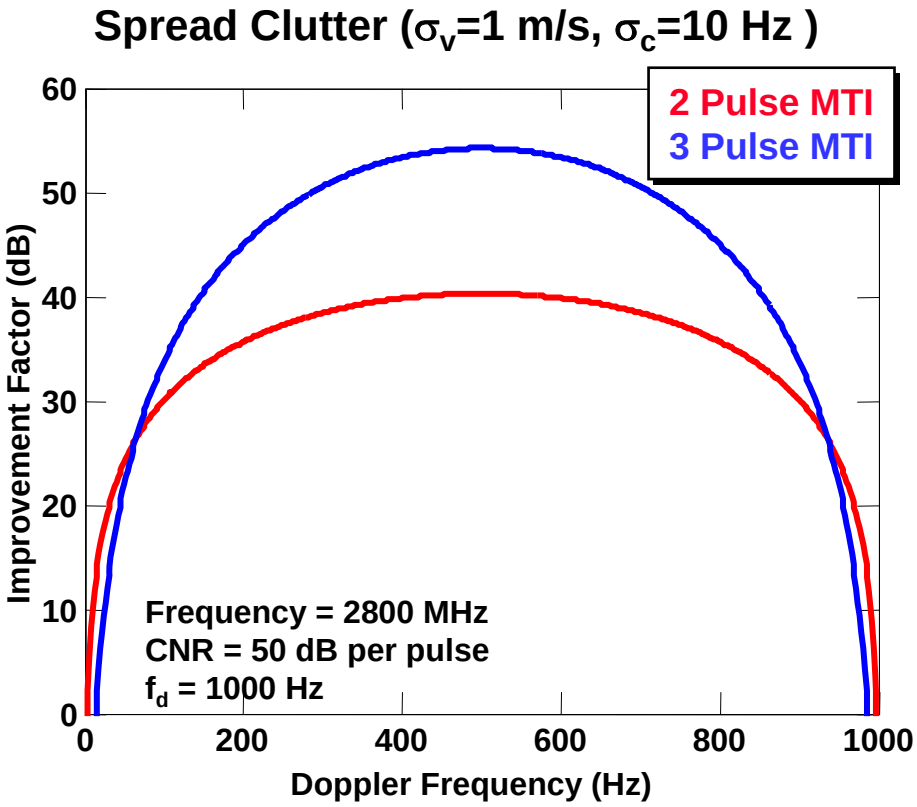
MTI Improvement Factor Examples

2-Pulse MTI

$$V_{output} = V_i - V_{i-1}$$

3-Pulse MTI

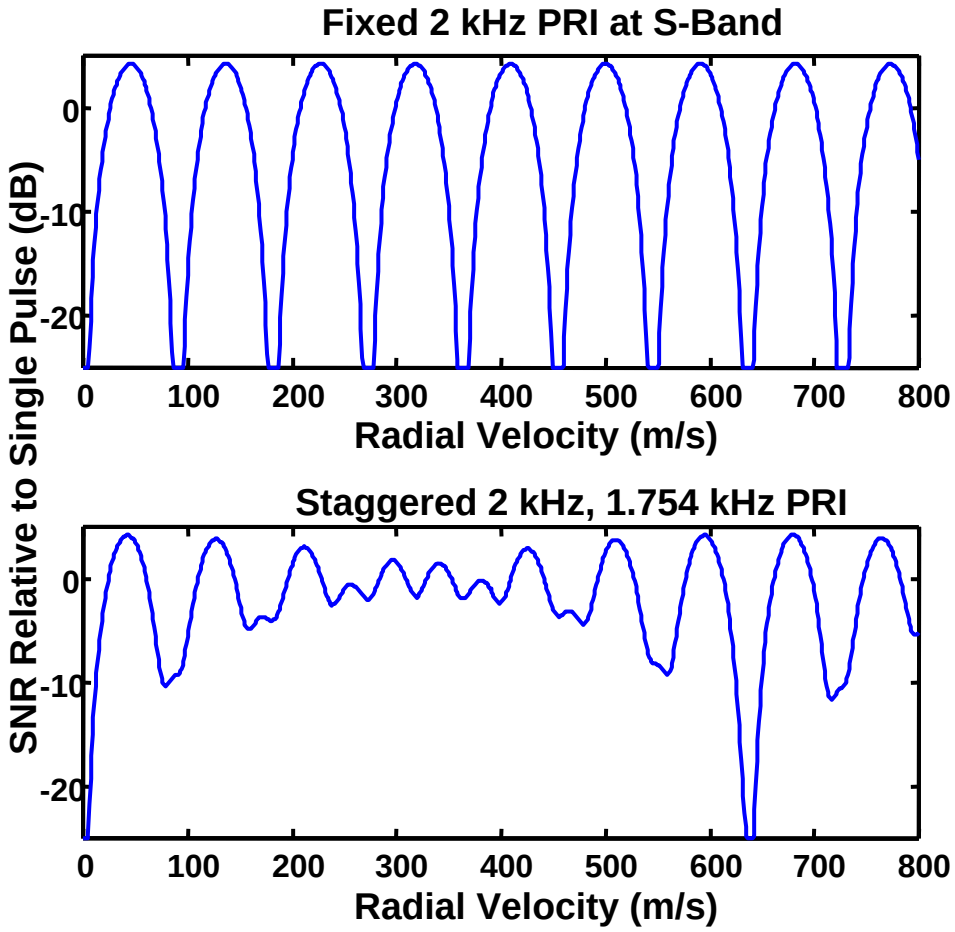
$$V_{output} = V_i - 2V_{i-1} + V_{i-2}$$



Three-pulse canceller provides wider clutter notch and greater clutter attenuation

Staggered PRFs to Increase Blind Speed

MTI Frequency Response

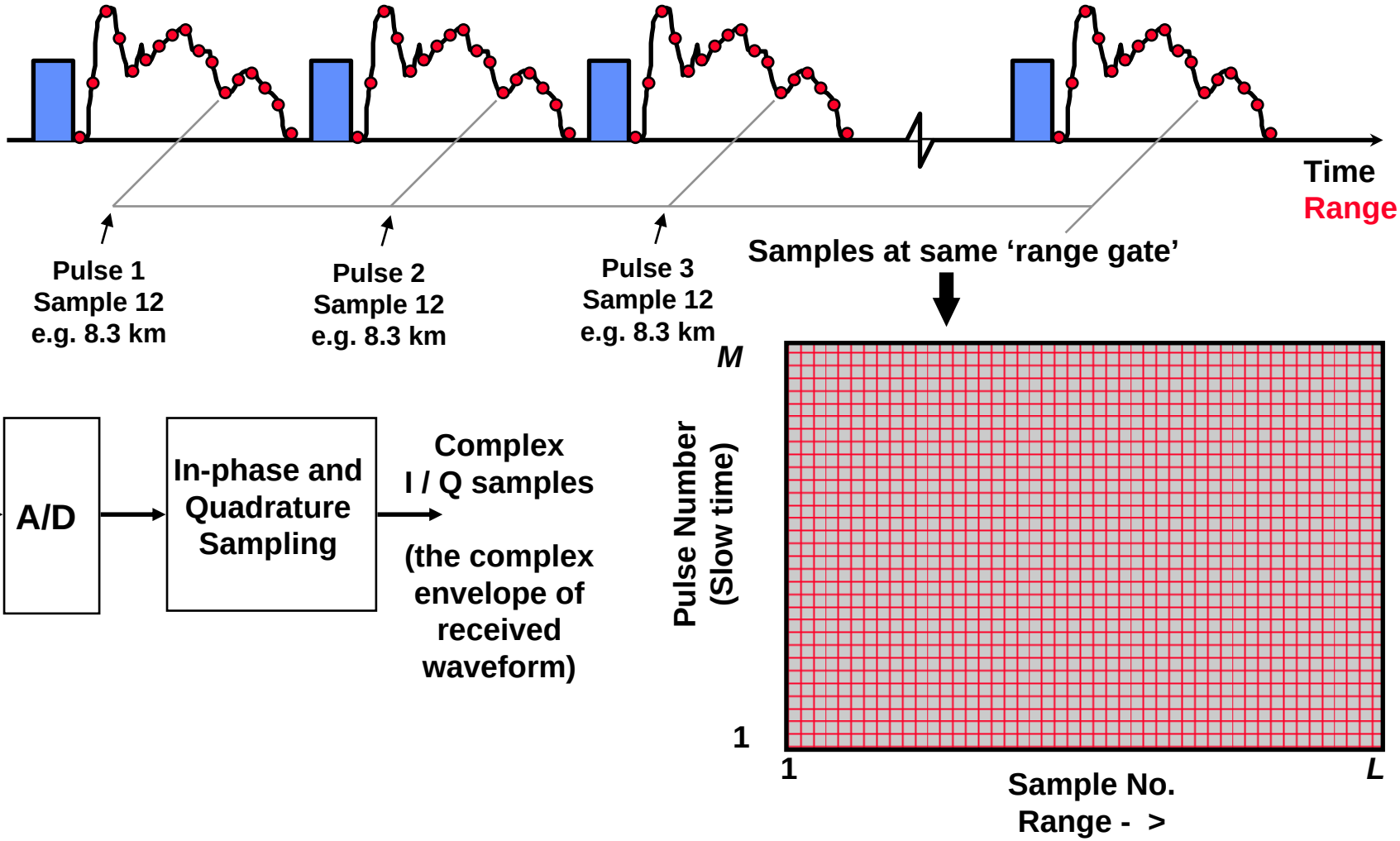


- Staggering or changing the time between pulses will raise the blind speed
- Although the staggered PRF's remove the blind speeds that would have been obtained with a constant PRF, there will be a new much higher blind speed

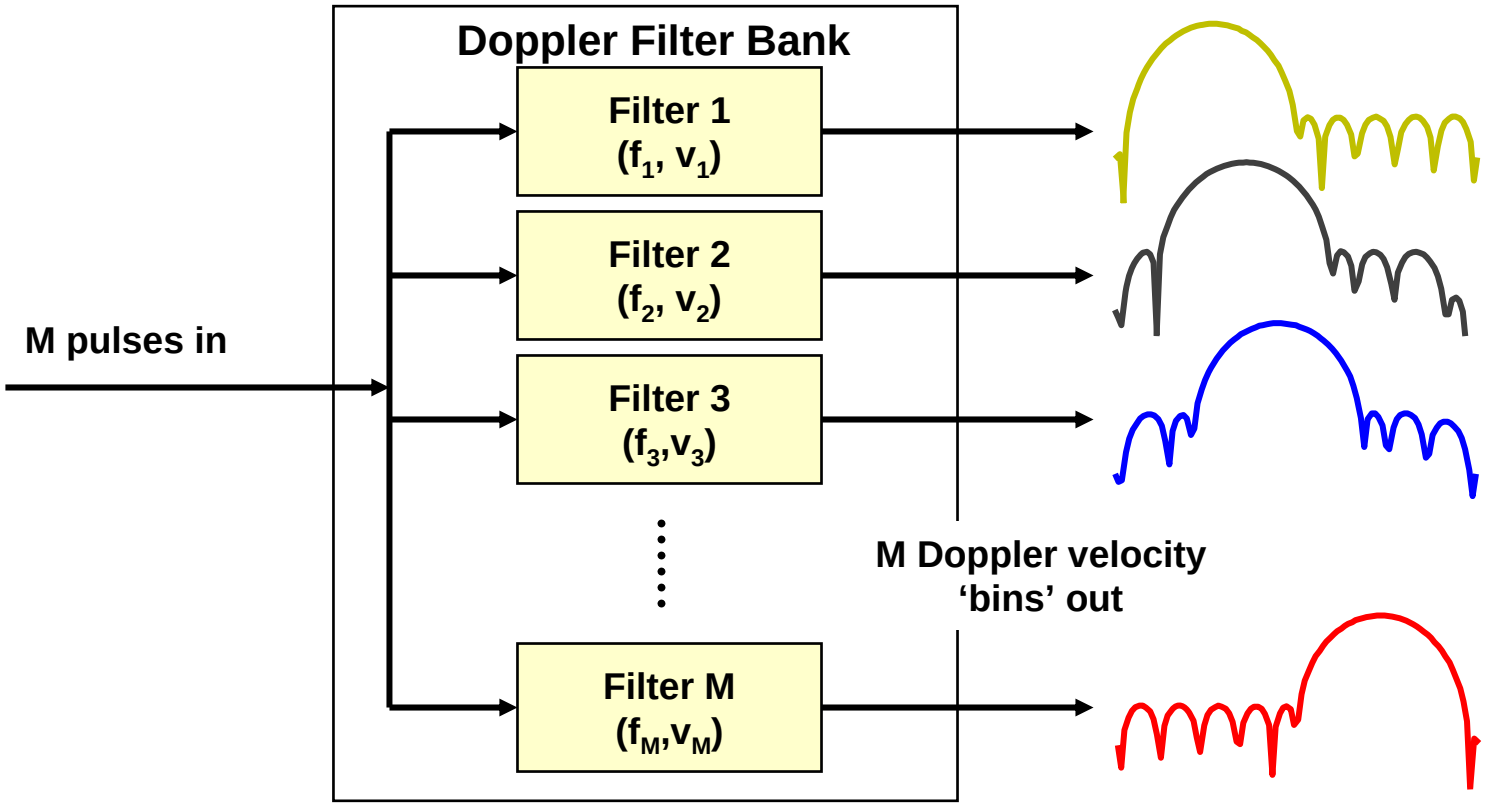
Outline

- Introduction
- Moving Target Indicator (MTI) Techniques
- Pulse Doppler Processing Techniques
  - Pulse Doppler Filtering Concept
    - Basic Concepts
    - Example - Moving Target Detector (MTD)
  - Range Doppler Ambiguities
  - Airborne Radar
- Summary

Data Collection for Doppler Processing

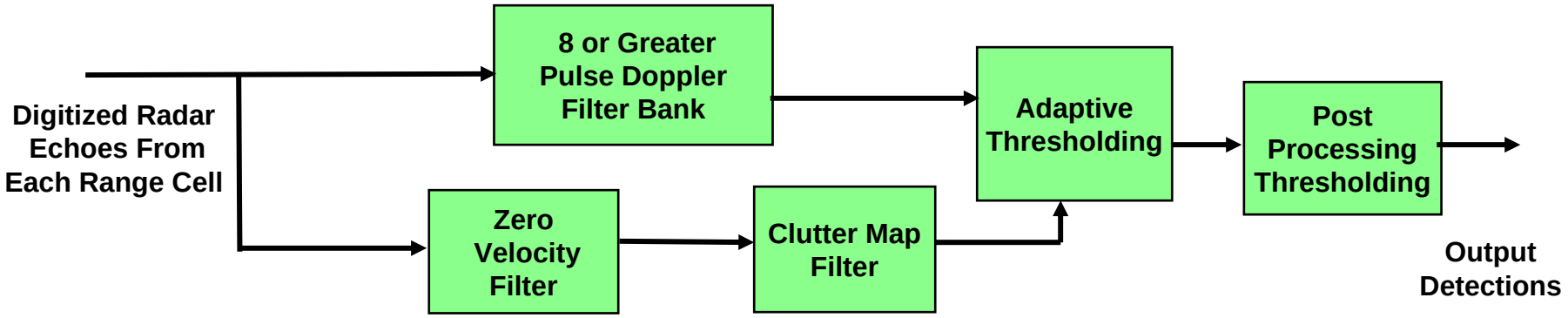


Pulse Doppler Processing



- Coherent integration of all pulses of a CPI
- Clutter rejection
- Resolving targets into different velocity segments and allowing for fine-grain target radial velocity estimation

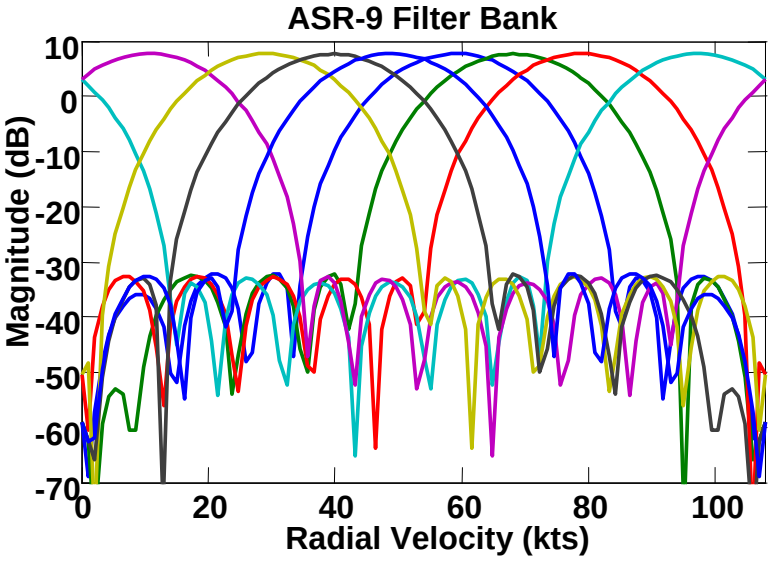
Moving Target Detector (MTD)

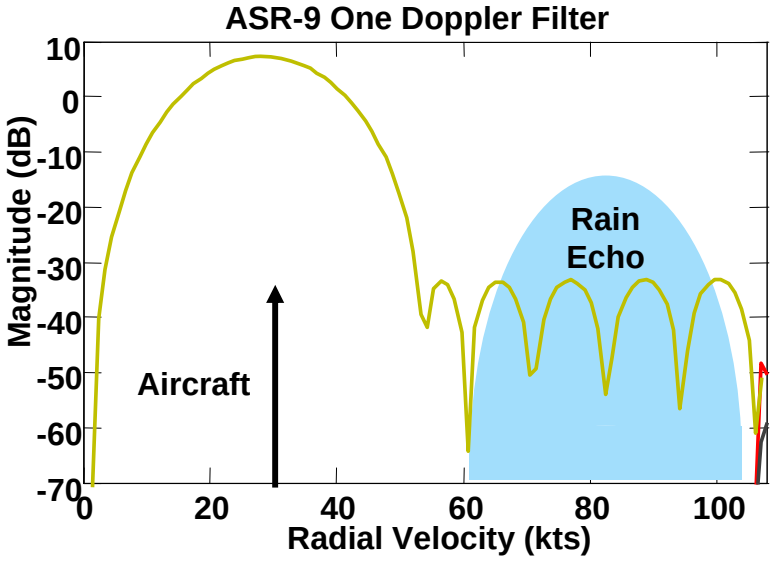


- Pulse Doppler filtering on groups of 8 or greater pulses with a fine grained clutter map.
- Aircraft are detected in ground clutter and / or rain with the Doppler filter bank & use of 2 PRFs.
- Birds and ground traffic are rejected in post processing, using Doppler velocity and a 2nd fine grained clutter map

ASR-9 8-Pulse Filter Bank

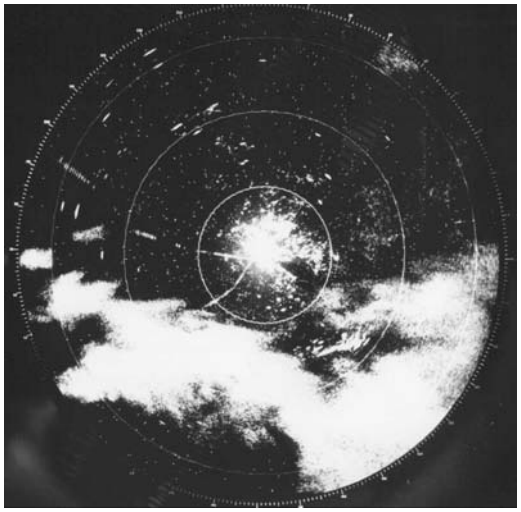
Courtesy of Northrop Grumman
Used with permission.



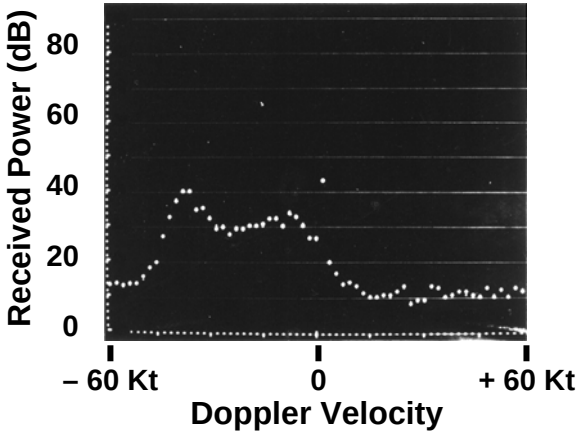


MTD Performance in Rain

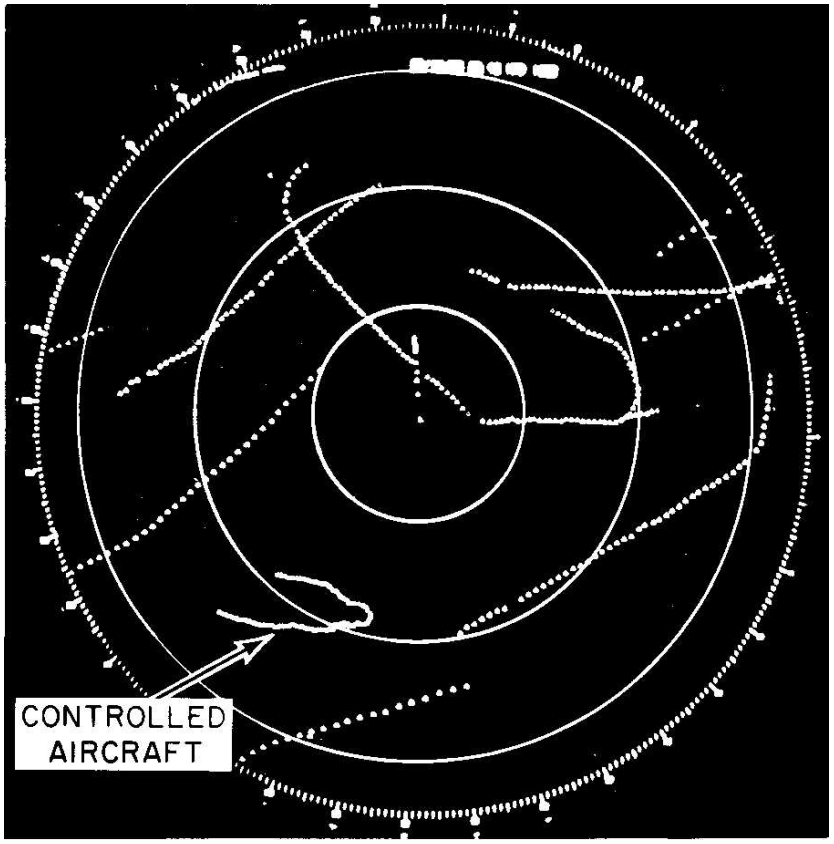
Unprocessed Radar Returns



Doppler Spectrum of Rain



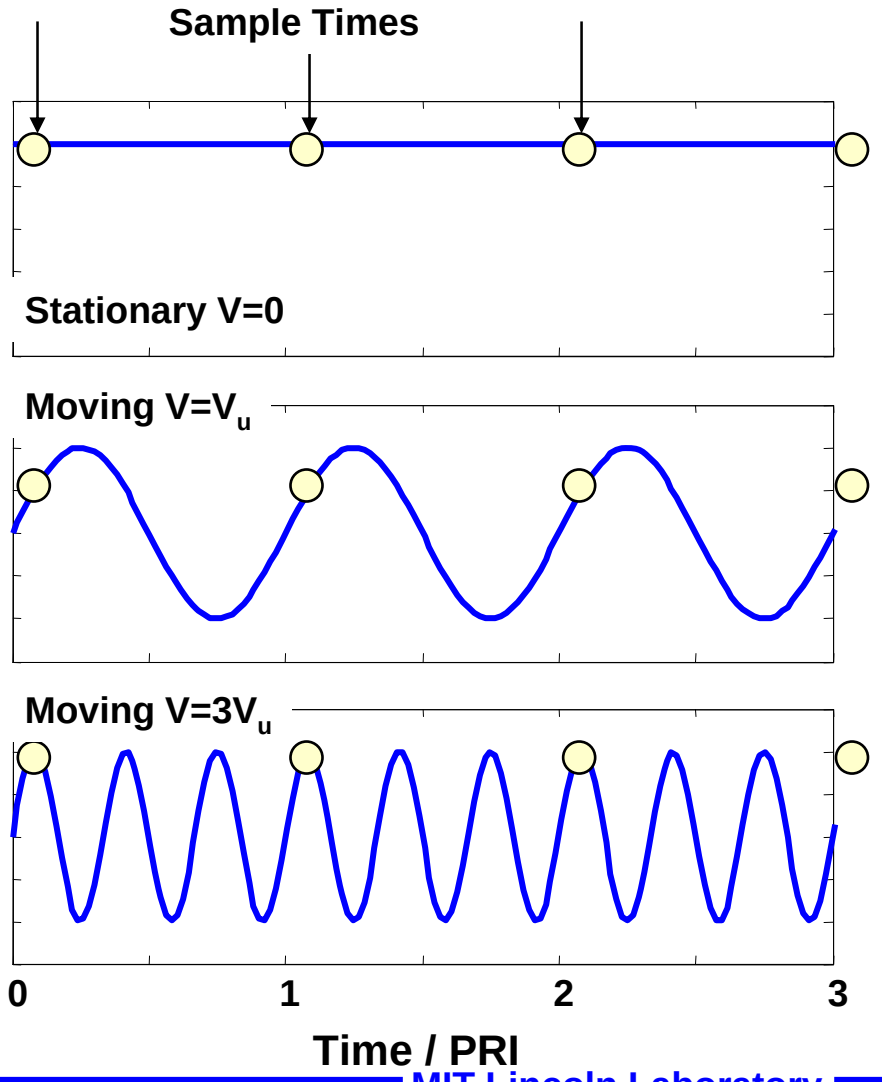
Time History of Radar Tracker Output
August 1975, FAA Test Center



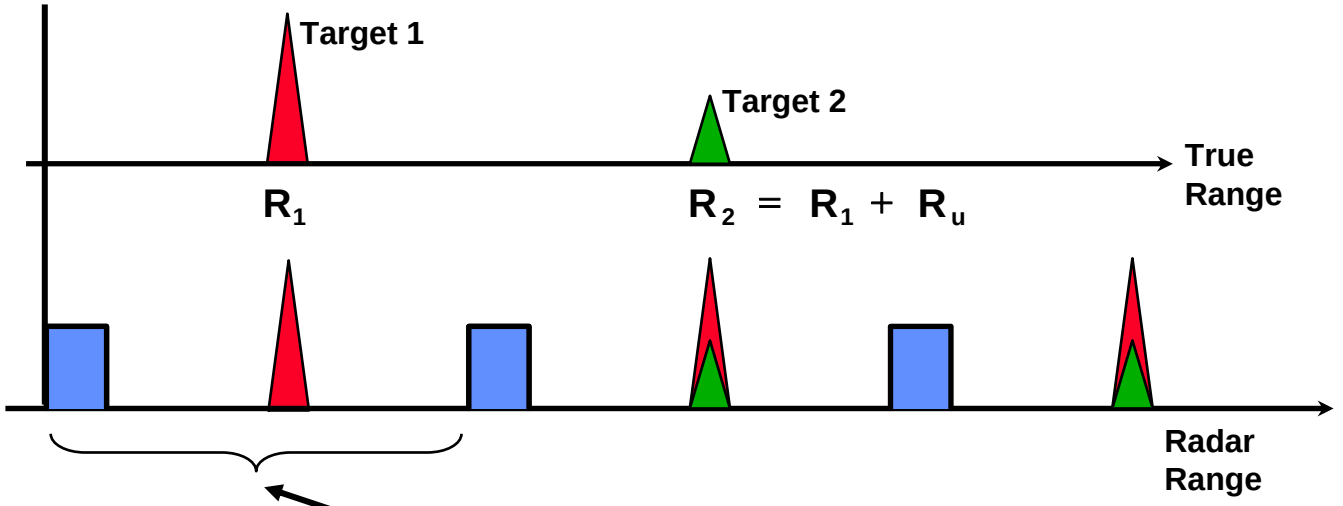
Doppler Ambiguities

- Pulse Doppler waveform samples target with sampling rate = PRF
- Sampling causes aliasing at multiples of PRF
- Two targets with Doppler frequencies separated by an integer multiple of the PRF are indistinguishable
- Unambiguous velocity

$$V_u = \frac{\lambda f_r}{2}$$



Range Ambiguities

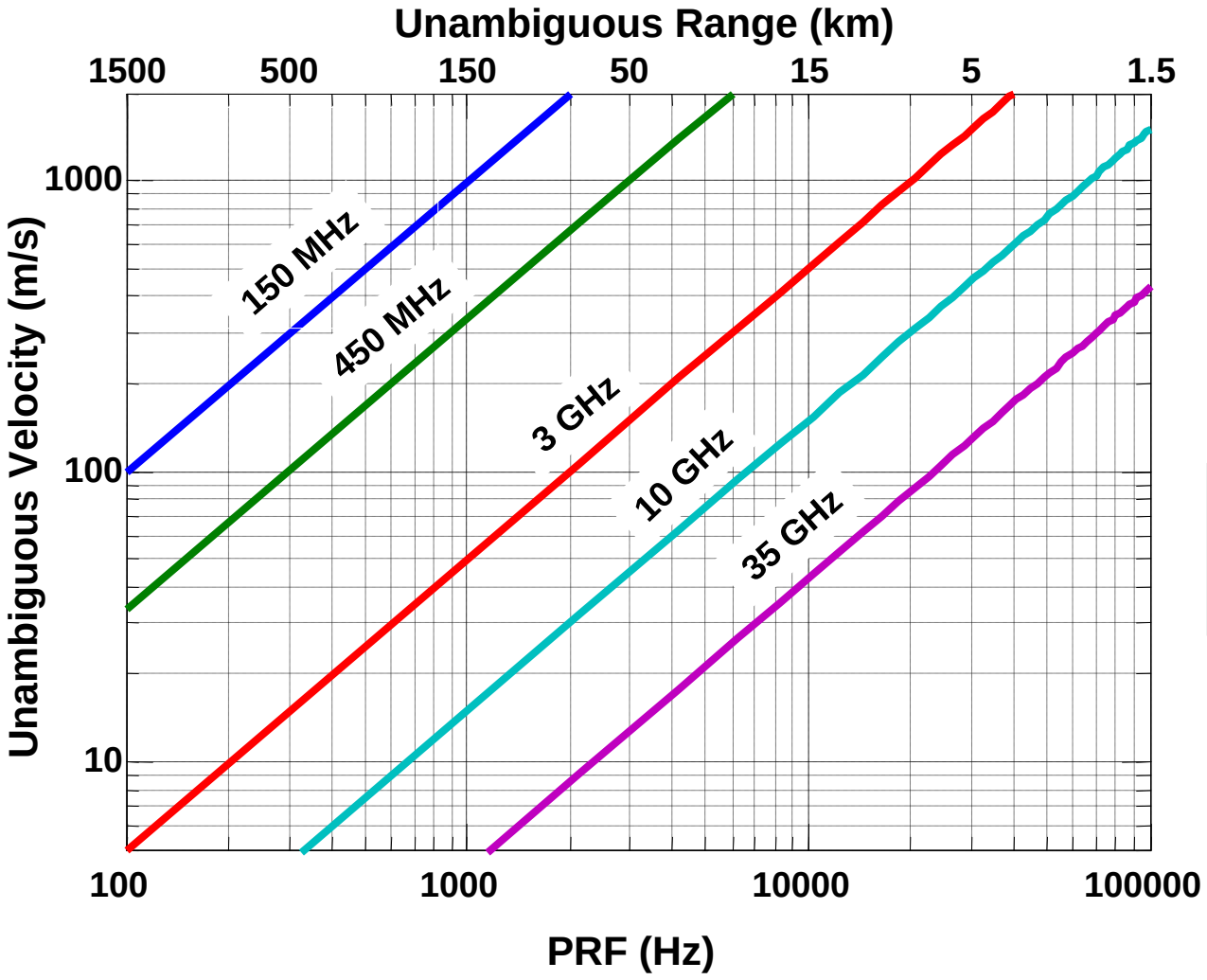


Unambiguous range

$$R_u = \frac{cT_r}{2}$$

- Range ambiguities occur when echoes from one pulse are not all received before the next pulse
- Strong close targets (clutter) can mask far weak targets

Unambiguous Range and Doppler Velocity



$$V_u = \frac{\lambda f_r}{2}$$

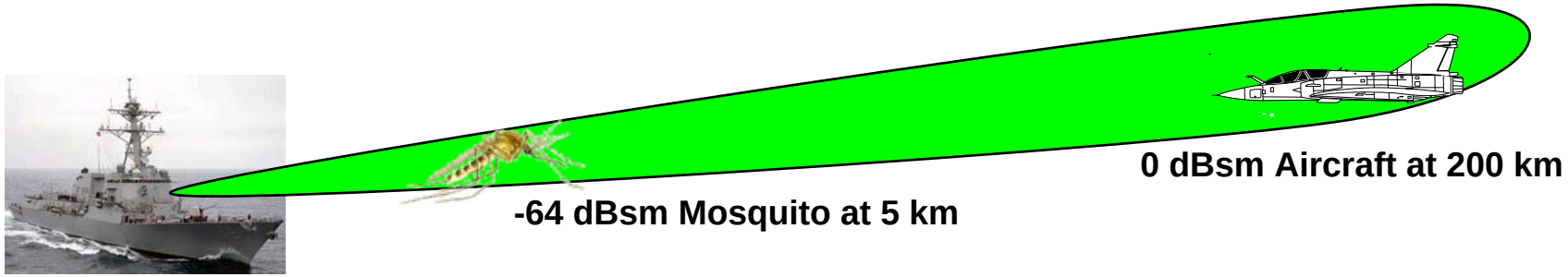
$$R_u = \frac{cT_r}{2} = \frac{c}{2 f_r}$$

Sensitivity Time Control (STC)

- **Deliberately reduce radar sensitivity at short ranges**

Why?

Both "Targets" Give Returns with Same Signal-to-Noise ratio



- **Attenuation of radar return by R^{-4} will result in constant SNR as a function of range for a constant cross section target**
- **STC cannot be used if the radar's waveform is ambiguous in range**
  - **Targets which are beyond the ambiguous range of the radar will be attenuated, because they folded over to close ranges**

Classes of MTI and Pulse Doppler Radars

	Low PRF	Medium PRF	High PRF
Range Measurement	Unambiguous	Ambiguous	Very Ambiguous
Velocity Measurement	Very Ambiguous	Ambiguous	Unambiguous

Low PRF

- Wind blown clutter may be a problem
- Can use STC

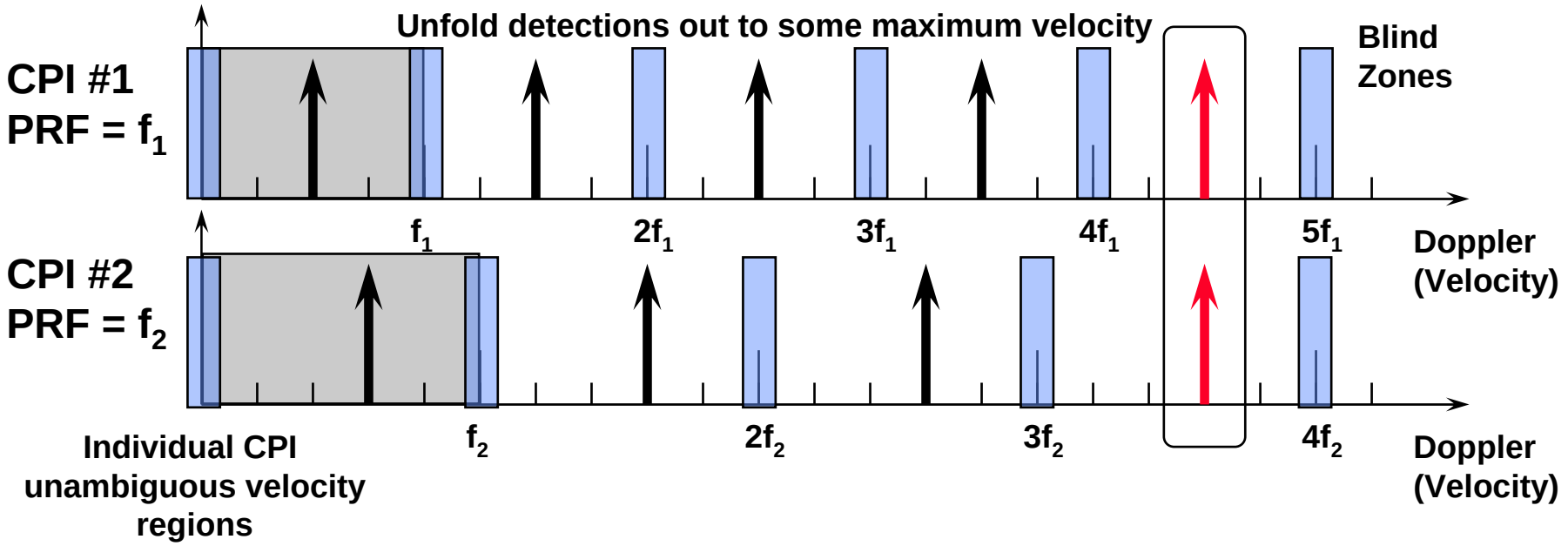
Medium PRF

- Wind blown clutter may be a problem
- Range eclipsing losses
- Far out targets compete with near in clutter
- Can't use STC
- Ambiguities hardest to remove

High PRF

- Range eclipsing losses
- Far out targets compete with near in clutter
- Can't use STC

Velocity Ambiguity Resolution

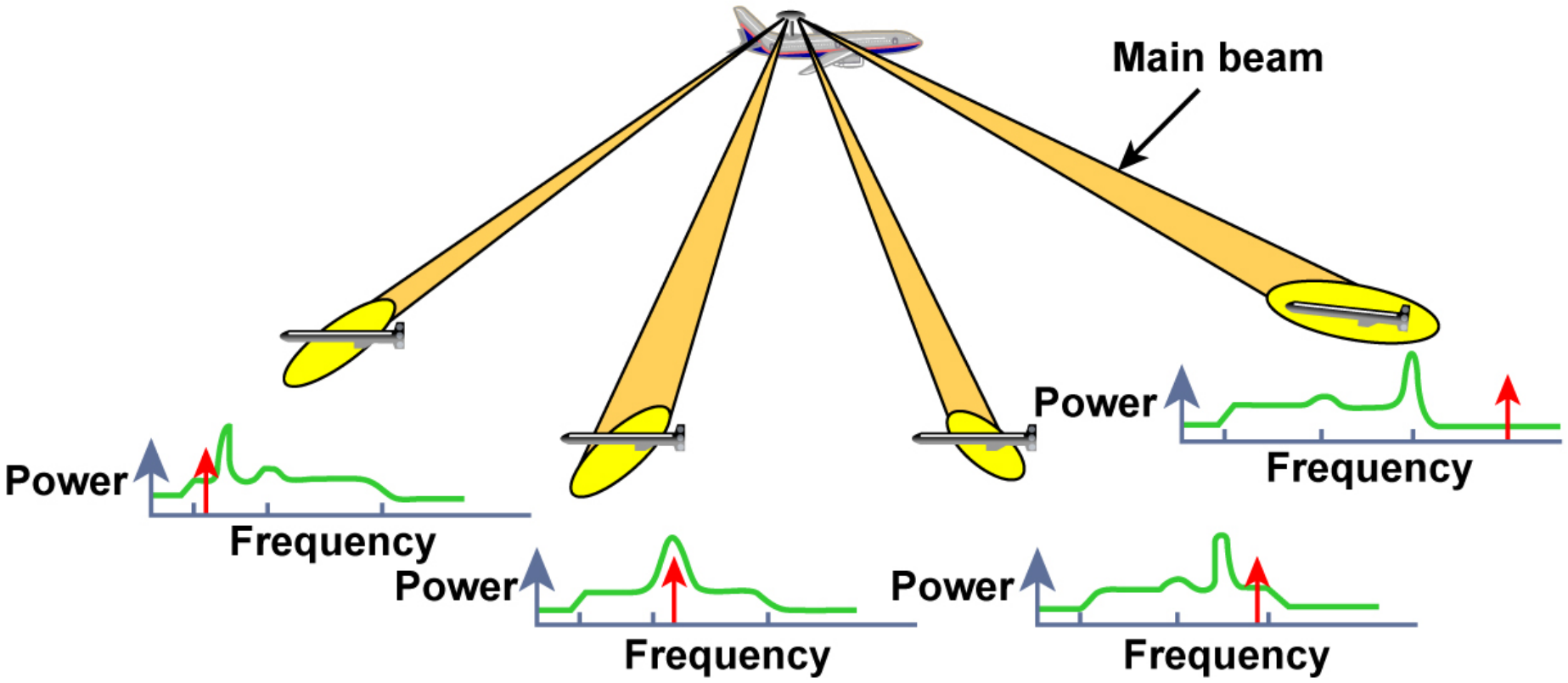


- Split dwell into multiple CPIs at different PRFs
  - Scan to scan, even pulse-to-pulse changes also possible
- Moves blind velocities to ensure detection of all non-zero velocity targets
- True target velocity is where best correlation across CPIs occurs
- Choose PRFs so that least common multiple occurs above desired maximum unambiguous velocity

Examples of Airborne Radar

Airborne Radar Clutter Characteristics

Illustrative example without Pulse-Doppler ambiguities



— Doppler frequency of mainbeam clutter depends on scan direction

— Doppler frequency of target depends on scan direction and target aspect angle

Figure by MIT OCW.

Airborne Radar Clutter Spectrum

Illustrative example without Pulse Doppler ambiguities

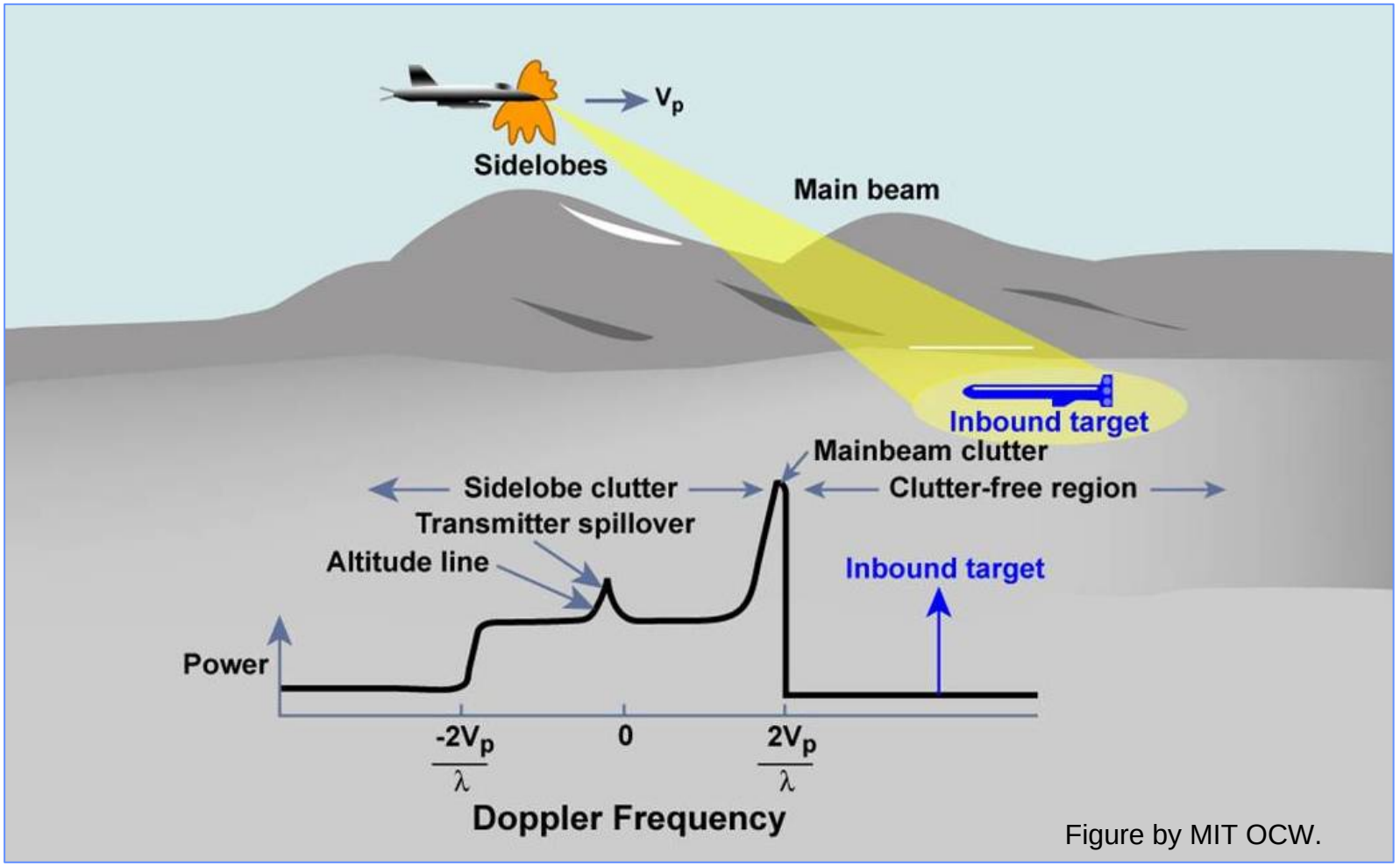


Figure by MIT OCW.

Airborne Radar Clutter Spectrum

Illustrative example without Pulse Doppler ambiguities

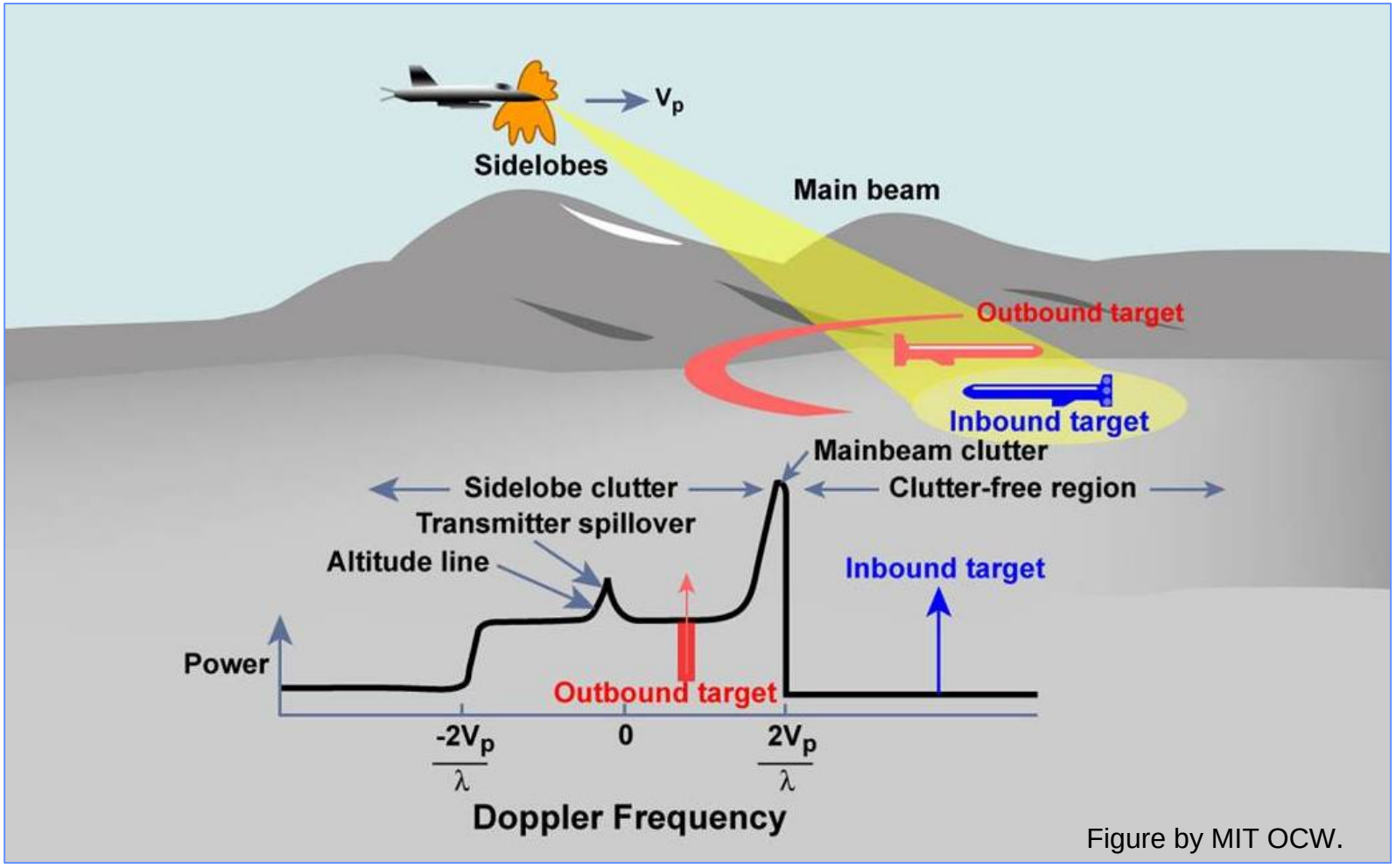
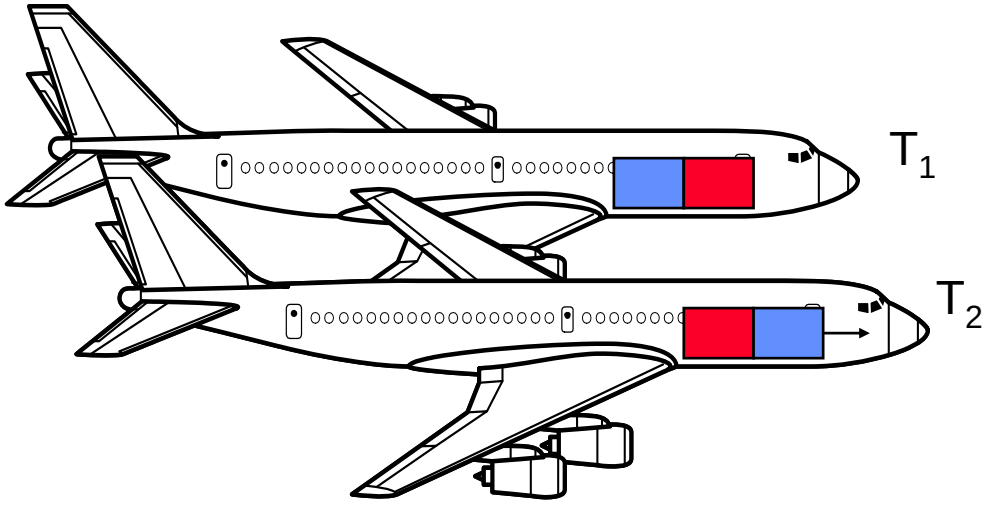


Figure by MIT OCW.

Displaced Phase Center Antenna (DPCA) Concept



If the aircraft motion is exactly compensated by the movement of the phase center of the antenna beam, then there will be no clutter spread due to aircraft motion, and the clutter can be cancelled with a two pulse canceller

Summary

- Moving Target Indicator (MTI) techniques
  - Doppler filtering techniques that reject stationary clutter
    - No velocity measurement
  - Blind speeds are regions of Doppler space where targets with that Doppler velocity cannot be detected
    - Changing the PRF between sets of pulses can alleviate the blind speed problem
  - MTI techniques have a limited capability to suppress rain clutter
- Pulse Doppler techniques
  - Used to optimally reject various forms of radar clutter
    - Measurement of target radial velocity
    - Moving Target Detector techniques are an example of optimum Doppler processing and associated adaptive thresholding
  - Ambiguities in range and Doppler velocity can be resolved by transmitting multiple bursts of pulses with different PRF's
  - Airborne radars use multiple PRF waveforms to suppress clutter

References

- Skolnik, M., Introduction to Radar Systems, New York, McGraw-Hill, 3rd Edition, 2001