Moving Target Indicator
Objectives

· Know how Pulsed Doppler radar works and how it is able to determine target velocity.
· Know how the Moving Target Indicator (MTI) determines target velocity.
· Be able to explain how pulse compression can provide a high-resolution radar return at the receiver.
Velocity Determination for Pulse Radars

A Basic Pulse Radar cannot determine velocity.

A However, simple radar modes enable us to calculate velocity.

- Moving Target Indicator (MTI).
  - Utilizes Phase Shift.
  - Pulse Doppler
  - Utilizes Frequency Shift.
Moving Target Indicator (MTI)

Measures changes in **Phase** of the return signal.
- Identifies targets in motion **ONLY**!

Phase Comparator.
- Samples Transmit and Return signal.
- Compares Phase.
  - In phase = largest positive value.
  - Out of Phase = largest negative value.
Moving target: range changes by $\frac{1}{4}$ wavelength

$\lambda/4$
The display can be a Scope.
Several sweeps are required to register moving target on the screen.
This produces a Butterfly effect on the screen due to simultaneous display of several sweeps.
Display

Another option is PPI. Then a delay line canceller is a must. It delays the echo by a pulse time. Then the present echo will be compared with previous echo to indicate moving targets. The bipolar resultant will be converted to unipolar using a full wave rectifier.
Moving Target Indicator (MTI)

- Delay line circuit saves previous phase evaluation.
- Cancellation circuit subtracts previous phase from current phase.
- Return from Stationary targets will have same phase comparison and be cancelled out.
- Return from Moving targets will have different phase comparison and will be retained / displayed.
MTI

\[ \text{Output} = \text{return} \times \text{phase} \]
The more common MTI radar employing a power amplifier is shown next.
Coherent MTI RADAR

- Pulse mod
- Duplexer
- Power amp
- Mixer
- Stalo $f_1$
- IF amp
- Phase detector
- Coho $f_c$
- Ref signal

$\text{Ref signal} \
\downarrow f_d \quad \downarrow f_c \quad \downarrow f_{c_1} \quad \downarrow f_{l + f_c} \quad \downarrow f_{l + f_c} \quad \downarrow f_{l + f_c}$
System Details

• Power amplifier: Triode, Tetrode, Klystron, TWT or CF Amplifier
• The combination of power oscillator and power amplifier makes it to be called as

MASTER OSCILLATOR POWER AMPLIFIER (MOPA)
Why master oscillator?

ÅBecause a reference signal can not be generated by a continuously running oscillator

ÅCoherent reference signal can be obtained by readjusting the phase of the COHO at the beginning of each sweep
Another type with Power Oscillator Transmitter is as shown next
Power Oscillator Transmitter

- Pulse mod
- Duplexer
  - $f_l + f_c ± f_d$
- Power amp
- Stalo $f_1$
- Mixer
  - $f_i$
- IF amp
  - $f_c ± f_d$
- Phase detector
  - $f_d$
- Ref signal
- Coho $f_c$
- $f_l + f_c$
Delay Line Canceller

- It is a time domain filter

- It operates at all ranges and does not require separate filter for each range resolution cell
Delay Line Canceller

$T = \frac{1}{PRF}$
Filter Characteristics

This rejects DC components of the clutter.

The video output:

\[ V_1 = K \sin (2\pi f_d t) \cos \Phi_0 \]

Previous:

\[ V_2 = K \sin (2\pi f_d (t-T)) \cos \Phi_0 \]

\[ V = V_1 - V_2 = 2K \sin (2\pi f_d T) \cos (2\pi f_d (t-T/2)) \cos \Phi_0 \]
The amplitude of the waveform is

$$2K \sin \frac{\pi f_d T}{1}$$
The response is zero whenever
\[ f_d T = n \]
Or
\[ 2V_r T / \varphi = n \]
\[ V_r = n \omega_p / 2 \]

When the response is zero means, the target is stationary or moving with this speed. Hence, the radar can not detect such a moving target. So, this speed is "BLIND SPEED."
Limitations of MTI

• Blind speeds are the limitations of the MTI.

• The target will not be visible to the radar though it is advancing towards it. This is very dangerous in most of the cases.
How to overcome?

Å If the blind speed is to be greater than maximum radial velocity expected, then $\beta_p$ is to be large.

Å Long wavelength and high PRF are preferable.

Å Then with more than one PRF, operate more than one $\beta$. 
Possible Solutions

- Long range MTI radars operate in L, S or higher bands.
- Operate with blind speeds and ambiguous doppler speed for the sake of accurate range estimation.
- The practical answer is: Keep the first blind speed out of the expected range of doppler frequency.
Practical Solution

- The standard technique is to operate at multiple frequencies.
- This is known as Staggered PRF in MTI.
Double Cancellation

It will have better clutter rejection null

\[
\text{Delay line canceller} \quad T = \frac{1}{f_p} \quad + \quad \Sigma \quad - \quad \text{Delay line canceller} \quad T = \frac{1}{f_p} \quad + \quad \Sigma \quad o/p
\]
The response $= 4 \sin^2 (f_d T)$
Discussion

- Zero response occurs only when the blind speeds of both radars coincide.
- The disadvantage is that region of low sensitivity might appear.
- The closer the ratio $T_1 : T_2$ is unity, the lower the value of the first blind speed.
- But first null in the vicinity of $f_d = 1/T_1$ becomes deeper. This is the trade off.
Pulse Doppler

• Attributes of pulse radar / technology of CW radar.
• Mixer added to Pulse Radar.
• Sample of transmitted and received signal are compared at mixer.
  • Mixer output is Doppler shift (velocity).
  • Doppler sorted into velocity categories.
  • Categories identified by color in display.
• Standard Weather Radar.
  • More rain / higher wind • higher Doppler.
Hurricane Hugo - Photo Image
Hurricane Hugo – Pulse Doppler
Pulse Doppler Radar

- Also used for weapon Fire Control systems
- Pulse Radar: ONE Antenna ONLY!
- High PRF
  - Many pulses / high frequency / large BW
  - Large volume of range and range rate info
  - High degree of accuracy
- Duty Cycle > 10%
Pulse Doppler System

Transmitter

Receiver

Doppler filter

Display

Antenna

\[ f_t \]

\[ f_r \]

\[ \Delta f \]
General Definition

A radar that increases its PRF high enough to avoid problems of blind speeds is called a pulse doppler radar.

But it may be acceptable to operate at a slightly lower PRF and accept both range and doppler ambiguities. Then it is medium PRF PDR.
Ambiguities possible

Å The MTI with no range ambiguities and many doppler ambiguities
Å The high PRF Pulse Doppler Radar with just the opposite: many range ambiguities and no doppler ambiguities.
Å The medium PRF Pulse Doppler Radar with some of each
Combo

- The equipment different between the two are no longer significant enough to distinguish one from the other.
- Pulse doppler radar generally receives much more clutter than an MTI radar.
- Pulse doppler radar requires much greater improvement factor than does an MTI radar of comparable performance.
Logical conclusions

- The antenna sidelobe clutter is large in a high PRF pulse doppler radar since there are many range ambiguous pulses simultaneously illuminating the clutter.

- With a duty cycle of 50%, the antenna sidelobes are simultaneously illuminating half the total clutter within the radar’s coverage.
Disadvantage

The large sidelobe clutter viewed by a pulse doppler radar is a reason why it requires a high improvement factor than an AMTI radar of equivalent performance.
To detect aircraft targets within the sidelobe clutter region, a bank of narrowband doppler filters with adaptive thresholds can be used. So antenna must have exceptionally low sidelobes.
Specific Advantage

The presence of a clutter free region is an important advantage of a high PRF pulse doppler radar especially if detecting high speed closing targets at long range is required.
Eclipsing Loss

Since the pulse doppler radar can not receive when it is transmitting the high duty cycle can result in a loss if the echo signal arrives when a pulse is being radiated and the receiver is turned off. This is called eclipsing loss.
The degree of eclipsing varies as the target range changes with time so eclipsing can cause periodic holes in the coverage.

A rapidly approaching target will not remain eclipsed for long so that detections will occur at a slightly shorter range when eclipsing is present.
A reduction of the duty cycle and an increase in the no. of range gates will reduce the effect of eclipsing.
Medium PRF - PDR

- It has both range and doppler ambiguities.
- It results in less clutter being seen by the antenna sidelobes than the high PRF radar since there are fewer pulse viewing ambiguous range cells.
- There is no clutter free region.
High PRF - PDR

Â No ambiguities in doppler frequency, no blind speeds but many range ambiguities
Â Range ambiguities can be resolved by transmitting three redundant waveforms each at a different PRF
Â Transmitter leakage and altitude return are removed by filtering
Main beam clutter is removed by a tunable filter.

High closing speed aircrafts are detected at long range in the clutter free region.

There is poor detection of low radial speed targets that are masked in the frequency domain by short range sidelobe clutter folded over in range.
Often only a single range gate is employed but with a large doppler filter bank.

For comparable performance, a much larger improvement factor is required than lower PRF systems since the high PRF results in more clutter being viewed by the antenna sidelobes.
• The antenna sidelobes must be quite low in order to minimize the sidelobe clutter.

• Range accuracy and the ability to resolve multiple targets in range are poorer than other radars.
Medium PRF - PDR

- Has both range and doppler ambiguities
- There is no clutter free region as in the high PRF system, so detection of high speed targets will not be as good as with the high PRF system.
Fewer range ambiguities mean that there will be less clutter seen in the antenna sidelobes so that targets with low relative speeds will be detected at long range than with a high PRF system.
The trade off of detectability of high speed targets for better detection of lower speed targets often makes the medium PRF system preferred over the high PRF system for airborne fighter/interceptor radar applications, if only a single system is used.
The altitude return can be eliminated by range gating. More range gates are required than in the high PRF system, but the number of doppler filters at each range gate is less. Seven or eight different PRFs must be used to insure that a target will have the proper doppler frequency to be detected on at least three PRFs in order to resolve range ambiguities.
For comparable range performance the large number of redundant waveforms means that the transmitter must be larger.

Better range accuracy an range resolution are available than with high PRF systems.

The antenna must have also low sidelobes to reduce the sidelobe clutter.
LOW PRF ï Airborne MTI

Å No range ambiguities but many doppler ambiguities (blind speeds)
Å Requires TACCAR and DPCA to remove effects of platform motion
Å TACCAR ï Time Averaged Compensation for Clutter Doppler Shift
Å DPCA ï Displaced Phase Center Antenna
It operates clutter free at long range where no clutter is seen due to curvature of earth.

Sidelobe clutter is usually not as important as it is in pulse doppler systems.

Best employed at UHF or perhaps L band.

Increase blind speeds and the lower effectiveness of platform motion compensation prevent its use at high microwave frequencies.
The lower RF of AMTI radar results in wider antenna beamwidth than a higher frequency (S band) pulse doppler radar whose mission is wide area air surveillance.

Because there are no range ambiguities to be resolved, redundant waveforms with multiple PRFs are not needed.
Å For comparable performance the required product of average power and antenna aperture is less than that for pulse doppler radars.
Å Usually simpler than pulse doppler radar.
Å Cost is generally much less than pulse doppler radar of comparable performance.
Å AMTI can not be used in fighter/interceptor X band radars for look down detection of targets in clutter.
Comparison

Å PDR
Å $F_r$ is estimated accurately
Å High PRF - not to have blind speeds
Å But time around echoes do exist
Å Power amplifier with high duty cycle
Å Range gates are used

Å MTI
Å Range is estimated accurately
Å Low PRF — no time around echoes
Å Blind speeds do exist
Å Delay line cancellers are used.
Salient Features

When the PRF is so high that the number of range ambiguities is too large to be easily resolved the performance of the PDR approaches that of CW radar.

But PDR advantage is that detection performance is not limited by transmitter leakage.
Limitation to MTI

ÅMTI improvement Factor
(S to C Ratio) $o/p$
--------------------------------
(S to C Ratio) $i/p$

ÅThis is averaged over radial velocities of all targets
Subclutter Visibility: To detect the target within the clutter of same power with specified detection and false alarm probability
Contdé

Â Clutter Visibility Factor : (S/C) after doppler filtering

Â Clutter Attenuation: At the clutter canceller, Ratio of i/p to o/p,
Contd..

Canceler voltage amplification for fixed target

Å Cancellation Ratio------------------------
Gain for a single pulse passing through unprocessed channel of canceler
Doppler Filter Bank

It is a set of contiguous filters for detecting targets as shown.

The advantages are quoted next.
Advantages

Å 1. Multiple Moving Targets can be separated from one another in a filter bank

Å When the clutter and target echo signal appear in different doppler shifts, the clutter echo need not interfere with the detection of the desired moving target.
A measure of target's radial velocity can be obtained. The ambiguity in the measurement can be resolved by a change in PRF.
Contdé

ÅThe narrowband doppler filters exclude more noise than do the MTI delay line cancelers described previously and provide coherent integration.
Limitation

The price paid is greater complexity, difficulty in achieving filters with low enough side lobes to reduce clutter and the need for a significant number of pulses to produce desirable filter characteristics.
The basic method for achieving a doppler filter bank is to employ the transversal filter. The time delay between each tap of the transversal filter is $T = 1/f_p$. 
The amplitude weights at each tap are all the same, the first-nulls of each filter are at the peaks of the adjacent filters.

The remainder of the frequency domain is covered by similar filters but with ambiguity and aliasing.
Lower sidelobes are needed if large values of the improvement factor are to be obtained with a doppler filter bank.

However, the main response is widened, the peak gain is reduced but the straddling loss at filter crossover is less.
The filter bank requires more pulses for good performance and it requires a larger signal to noise ratio if the true radial velocity is to be extracted when two or more prfs are employed.
Limitation to MTI Performance

The reasons are:
1. Antenna Scanning Modulation
2. Internal fluctuation of clutter
3. Equipment instabilities
4. Limiting.
The limitations cause the clutter spectrum to widen. More clutter energy is passed through the doppler filters which lowers the improvement factor.
JSTAR

**JSTAR –**

Desert Storm MTI
How butterfly effect is produced on the screen in the case of MTI radar?

When MTI radar signal is processed, the indication represents only the moving target. This is given to a Plan Position Indicator. The screen will have some persistence. This display remains for some time. During this time, if the echo for the next pulse is processed and is displayed, it will show a slight change from the previous display. Like this, after several pulses, the screen consists of several slightly changed displays which appears like a butterfly.
In the case of PPI, what is the need of converting bipolar signal to unipolar signal?

A PPI displays range versus azimuth. The range signal input must be only positive. But the receiver output is going to be bidirectional. Because the phase of the present time echo may be sometimes more and less other times when compared to previous time echo. So, using a FWR, this bipolar signal is converted to a unipolar signal.
Question 3

What happens if the duty cycle goes below 10% for pulse Doppler radar?

If the duty cycle is below 10%, the amount of power contained within that will be very small. So, far off target will give rise to very little echo at the receiver which may not be detected.
Question 4

How multiple moving targets are separated from one another by using Doppler filter bank?

A doppler filter bank is a frequency selective filter bank. Each filter selects only a narrow range of frequencies which correspond to narrow range of velocities. As the targets are likely to be moving at different velocities, the echoes from different targets enter into different receivers due to these filter banks.
Question 5

Why first blind speed should be kept out of the expected range of Doppler freq?

The blind speed can not be avoided in the MTI system. To avoid this blind speed, the delay line canceller is designed so that it is definitely higher than the maximum velocity of the expected targets in a specific location.