Unit II - MTI And Pulse Doppler Radar

S-1 *Introduction to Doppler Radar* and

Introduction to MTI Radar

S2-Delay line cancelers

RADAR Classification

- Radars can be classified into the following **two types** based on the type of signal with which Radar can be operated.
- Pulse Radar

  - Basic Pulse Radar

  -Moving Target Indication Radar

- Continuous Wave Radar

  -Unmodulated Continuous Wave Radar

  -Frequency Modulated Continuous Wave Radar

Pulse Radar

Basic Pulse Radar

- The Radar, which operates with pulse signal for detecting stationary targets, is called the **Basic Pulse Radar** or simply, Pulse Radar. It uses single Antenna for both transmitting and receiving signals with the help of Duplexer.
- Antenna will transmit a pulse signal at every clock pulse. The duration between the two clock pulses should be chosen in such a way that the echo signal corresponding to the present clock pulse should be received before the next clock pulse.

Pulse Radar

Moving Target Indication Radar

- The Radar, which operates with pulse signal for detecting non-stationary targets, is called Moving Target Indication Radar or simply, **MTI Radar**. It uses single Antenna for both transmission and reception of signals with the help of Duplexer.
- MTI Radar uses the principle of **Doppler effect** for distinguishing the non-stationary targets from stationary objects.

Continuous Wave Radar

Unmodulated Continuous Wave Radar

- The Radar, which operates with continuous signal (wave) for detecting non-stationary targets is called Unmodulated Continuous Wave Radar or simply, **CW Radar**. It is also called CW Doppler Radar.
- This Radar requires two Antennas. Of these two antennas, one Antenna is used for transmitting the signal and the other Antenna is used for receiving the signal. It measures only the speed of the target but not the distance of the target from the Radar.

Continuous Wave Radar

Frequency Modulated Continuous Wave Radar

- If CW Doppler Radar uses the Frequency Modulation, then that Radar is called the Frequency Modulated Continuous Wave **(FMCW)** Radar or FMCW Doppler Radar. It is also called Continuous Wave Frequency Modulated Radar or CWFM Radar.
- This Radar requires two Antennas. Among which, one Antenna is used for transmitting the signal and the other Antenna is used for receiving the signal. It measures not only the speed of the target but also the distance of the target from the Radar.

Doppler Frequency Shift

- Doppler effect that changes the frequency of the electromagnetic signal that propagates from the radar to a moving target and back to the radar.
- Total Phase change in the two way Propagation Path is $\phi = 2\pi \times \frac{2R}{\lambda} = 4\pi R/\lambda$
- Angular frequency is rate of change of phase w.r.to time

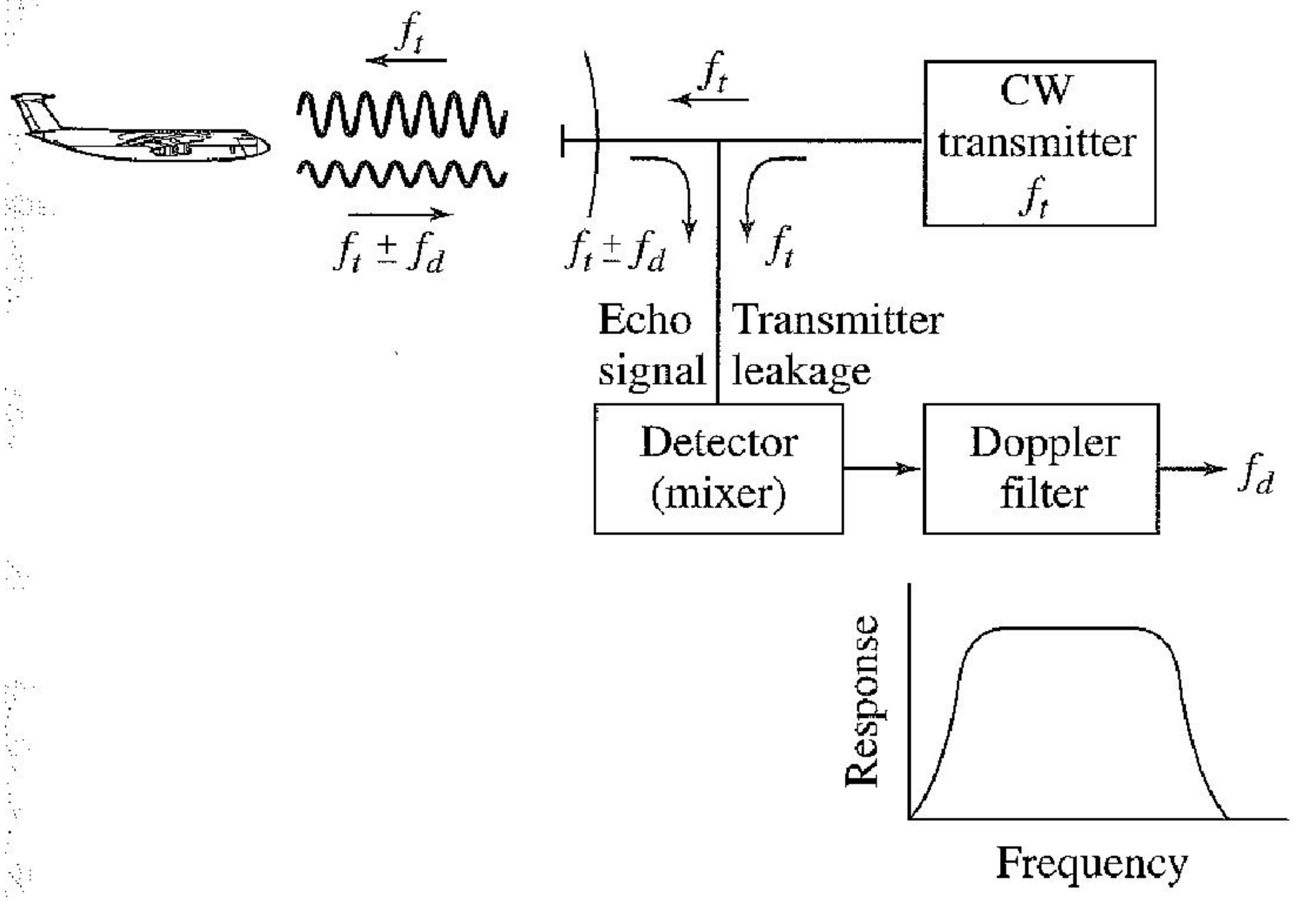
$$\omega_d = \frac{d\phi}{dt} = \frac{4\pi}{\lambda}\frac{dR}{dt} = \frac{4\pi v_r}{\lambda} = 2\pi f_d$$

where $v_r = dR/dt$ is the radial velocity (meters/second),

- Doppler frequency shift is given by $f_d = \frac{2v_r}{\lambda} = \frac{2f_t v_r}{c}$

Simple CW Doppler Radar Block Diagram

- CW Doppler Radar transmits while it receives
- $f_t + f_d$ – Closing Target
- $f_t - f_d$ – Receding target
- Doppler filter rejects higher frequency
- Lower cut off freq- Removes Clutters and echoes
- Higher cut off freq- Maximum Radial velocity expected of moving targets



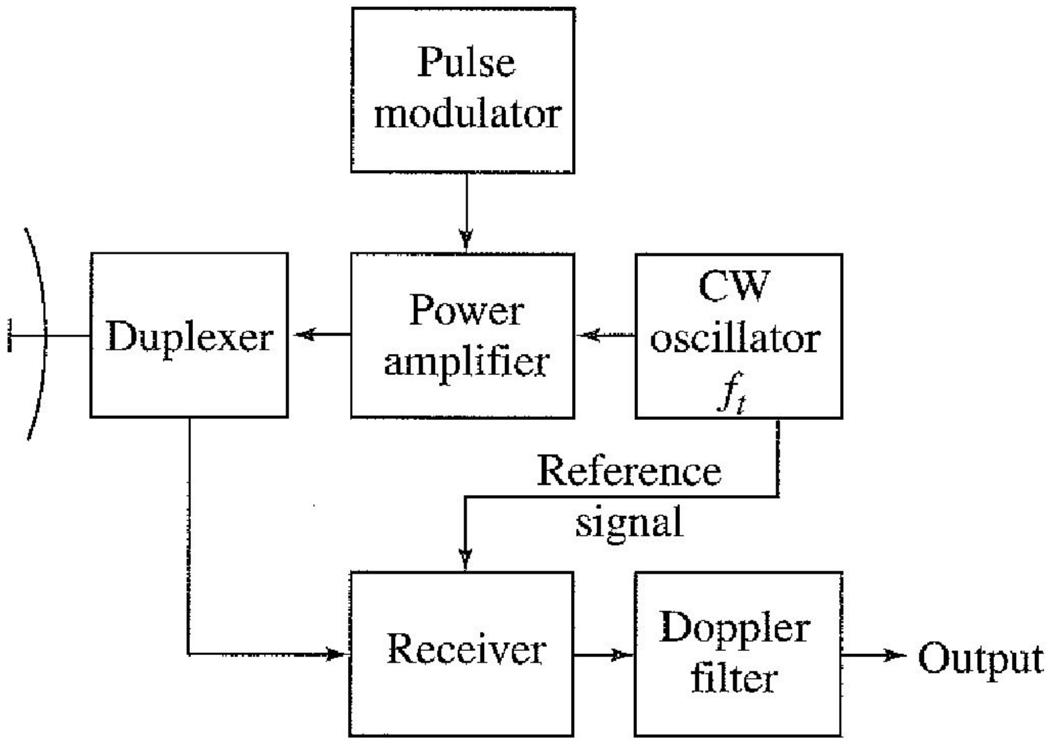
Pulse Radar

- Power amplifier is turned on and off (modulated) to generate a series of high power pulses.
- The received echo signal is mixed with output of oscillator's coherent reference to check change in echo signal frequency
- Received signal is

$$V_{\text{rec}} = A_r \sin\left[2\pi f_t\left(1 + \frac{2v_r}{c}\right)t - \frac{4\pi f_t R_0}{c}\right]$$

- Received signal is heterodyned with ref signal $A_{\text{ref}} \sin 2\pi f_t t$

$$V_d = A_d \cos\left(2\pi f_d t - 4\pi R_0/\lambda\right)$$



Echo Pulses

If the radar pulse width is long enough and if the target's doppler frequency is large enough, it may be possible to detect the doppler frequency shift on the basis of the frequency change within a single pulse. If Fig. 3.4a represents the RF (or IF) echo pulse train, Fig. 3.4b is the pulse train when there is a recognizable doppler frequency shift. To detect a doppler shift on the basis of a single pulse of width τ generally requires that there be at least one cycle of the doppler frequency f_d within the pulse; or that $f_d\tau > 1$. This condition, however, is not usually met when detecting aircraft since the doppler frequency f_d is generally much smaller than $1/\tau$. Thus the doppler effect cannot be utilized with a *single* short pulse in this case. Figure 3.4c is more representative of the doppler frequency for aircraft-detection radars. The doppler is shown sampled at the pulse repetition frequency (prf). More than one pulse is needed to recognize a change in the echo frequency due to the doppler effect. (Figure 3.4c is exaggerated in that the pulse width is usually small compared to the pulse repetition period. For example, τ might be of the order of 1 μs, and the pulse repetition period might be of the order of 1 ms.)

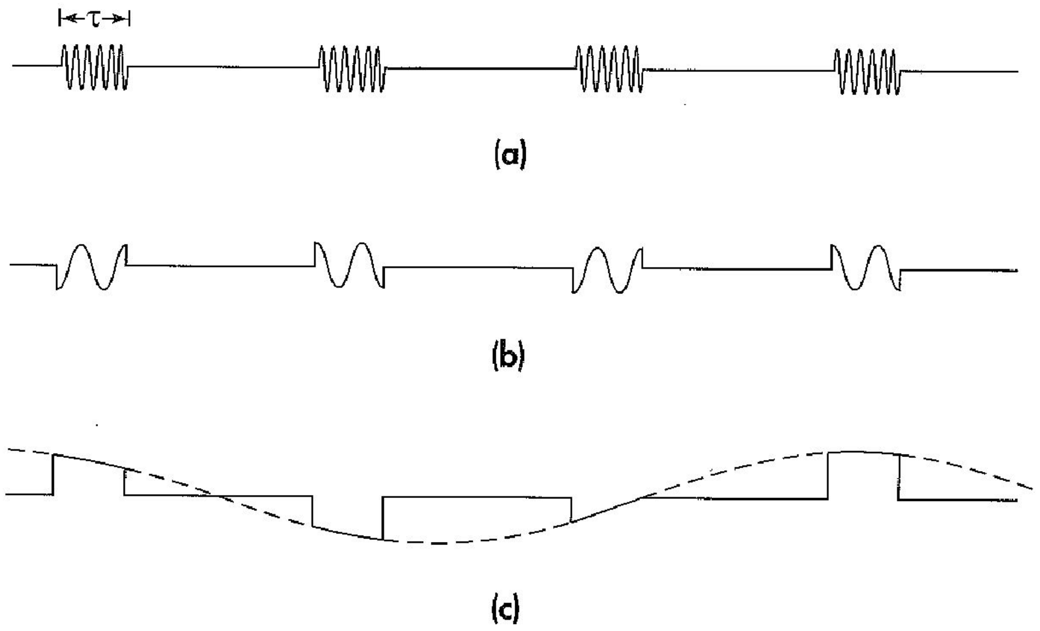
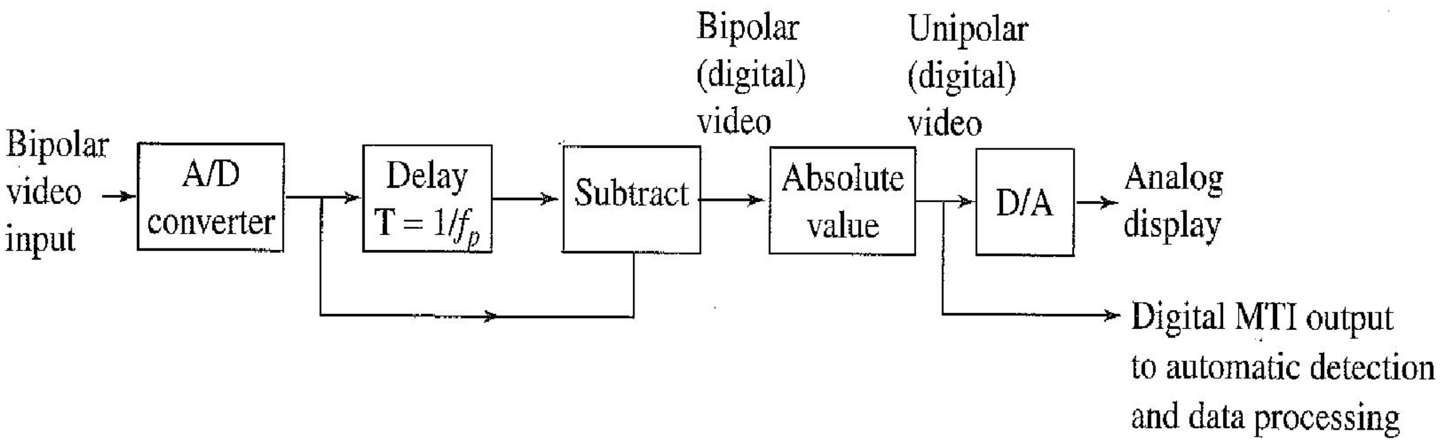


Figure 3.4 (a) Representation of the echo pulse train at either the RF or IF portion of the receiver; (b) video pulse train after the phase detector when the doppler frequency $f_d > 1/\tau$; (c) video pulse train for the doppler frequency $f_d < 1/\tau$, which is usually the case for aircraft-surveillance radar. The doppler frequency signal is shown dashed in (c), as if it were CW. Note that the pulses in (c) have an exaggerated width compared to the period of the doppler frequency.

Delay Line canceler

- Single Delay Line canceler



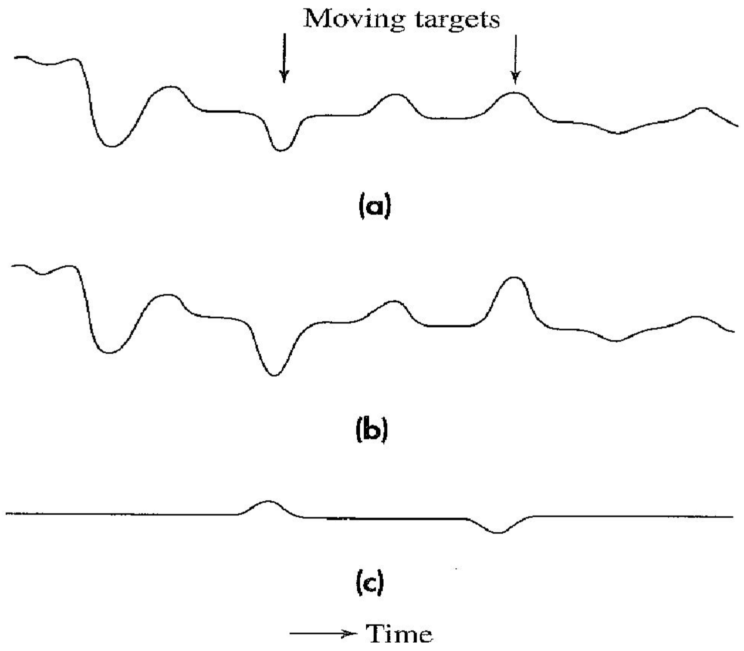
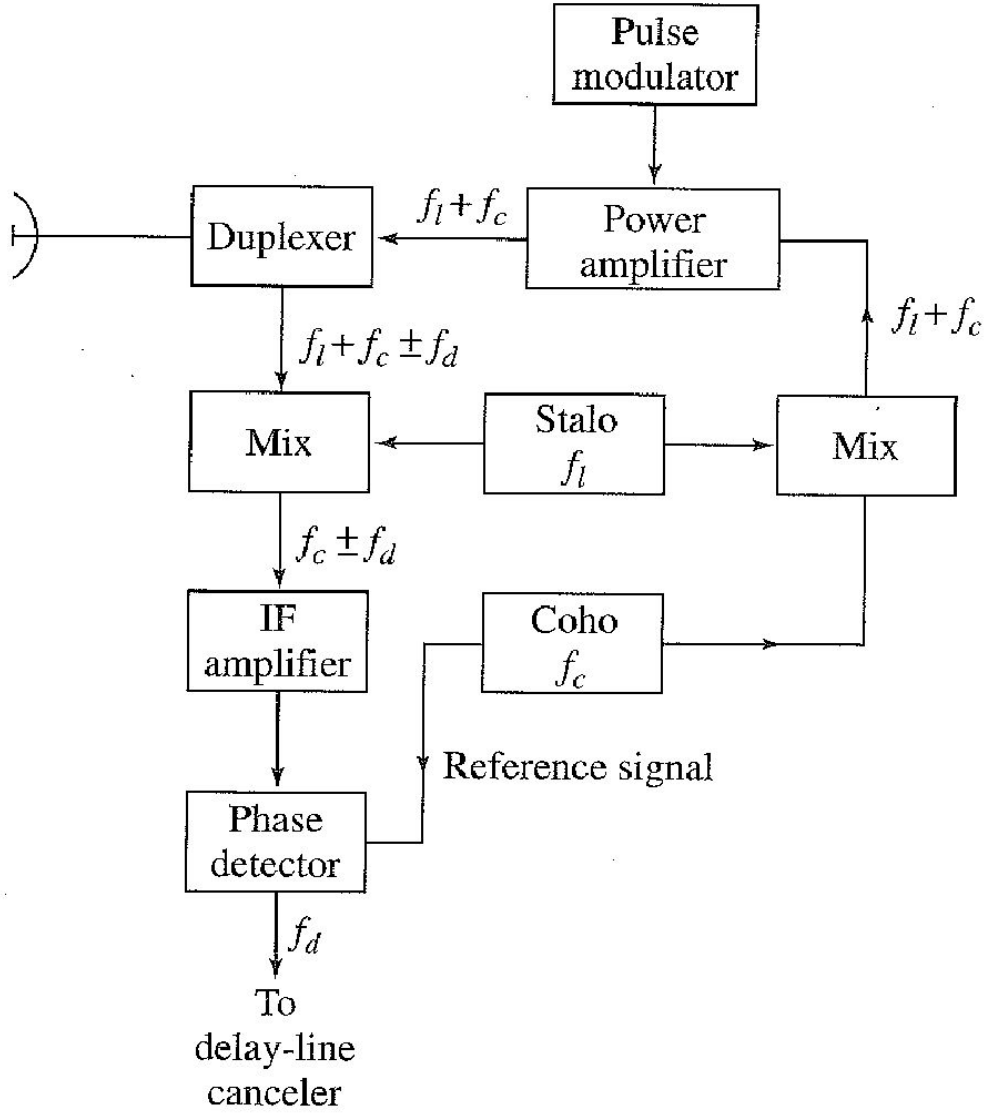


Figure 3.5 Two successive sweeps, (a) and (b), of an MTI radar A-scope display (amplitude as a function of time, or range). Arrows indicate the positions of moving targets. When (b) is subtracted from (a), the result is (c) and echoes from stationary targets are canceled, leaving only moving targets.

- Output of the MTI radar is bipolar video
- Delay line-Digital memory

MTI Block Diagram

- Local Osc. of an MTI radar system should be more stable. Change in phase may results as a uncancelled clutter as a moving target.
- Stalo-Stable local Osc.
- IF stage is designed as a Matched filter
- Coho-Coherent Osc. (Ref signal-phase of Tx signal)
- Stalo+Coho = Receiver-exciter portion (better stability)
- Delay line canceller acts as HPF to separate echoes of moving target from echoes of clutter



MTI

- Klystron and travelling wave tube amp. Used as vaccum tube amp. In MTI radar
- Crossed field amplifier-Noisier and less significant large clutter echo cancellation
- Triode and tetrode – UHF and lower frequencies
- Solid state transistor-Lower freq, stable, Don’t need pulse modulator
- Magnetron-Used in 1950’s-tx pulse is used to lock the phase of coho.

Delay line cancellers

- The frequency response of single delay line cancellers

$$H(f) = 2 \sin (\pi f_d T_p)$$

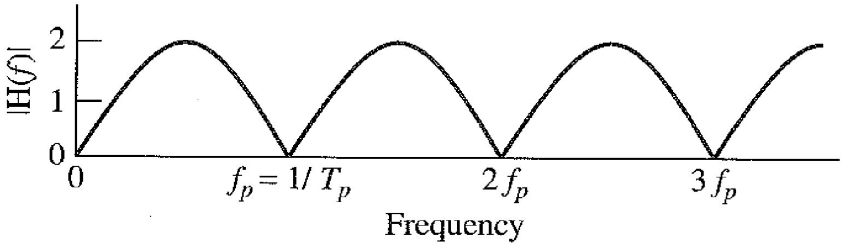
- Limitation of single delay line cancellers

The single delay-line canceler is a filter that does the job asked of it: it eliminates fixed clutter that is of zero doppler frequency. Unfortunately, it has two other properties that can seriously limit the utility of this simple doppler filter: (1) the frequency response function also has zero response when moving targets have doppler frequencies at the prf and its harmonics, and (2) the clutter spectrum at zero frequency is not a delta function of zero width, but has a finite width so that clutter will appear in the pass band of the delay-line canceler. The result is there will be target speeds, called *blind speeds,* where the target will not be detected and there will be an uncanceled clutter residue that can interfere with the detection of moving targets. These limitations will be discussed next.

Blind speeds

Blind Speeds The response of the single delay-line canceler will be zero whenever the magnitude of sin $(\pi f_d T_p)$ in Eq. (3.10) is zero, which occurs when $\pi f_d T_p = 0, \pm\pi, \pm 2\pi, \pm 3\pi, \ldots$. Therefore,

$$f_d = \frac{2v_r}{\lambda} = \frac{n}{T_p} = nf_p \qquad n = 0,1,2,\ldots \qquad [3.11]$$



Methods to reduce the effects of blind speed

Blind speeds occurs because of the sampled nature of pulsed radar waveform.

1.Operate the radar at long wavelengths (Lower frequencies)

2.Operate with high PRF
3.Operate with more than one PRF

4.Operate with more than one RF frequency

Methods to reduce the effects of blind speed

- VHF region (150 MHz)

-Resolution and range is poor due to narrow BW and large beamwidth

-Frequency is crowded with broadcasting FM & TV

-Low altitude coverage is poor

- High RF:

-maximum unambiguous range is small

- Multiple PRF

-Used in air surveillance radar-civil air traffic control

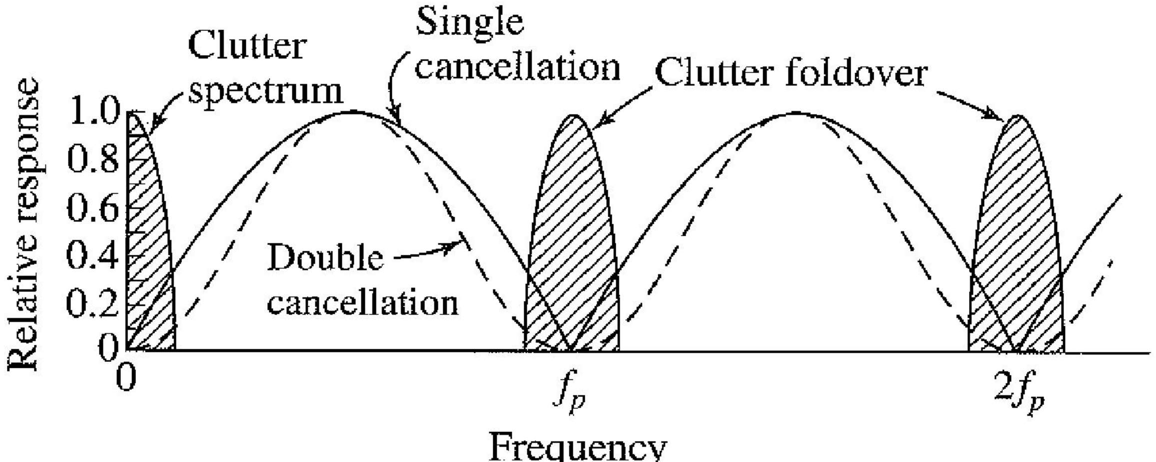
-multiple time around clutter echoes not cancelled

- Multiple RF

-need greater system bandwidth

Clutter attenuation

- Insufficient attenuation of clutter due to finite width clutter spectrum (non zero)
- Due to internal motions of the clutter, instabilities of the stalo and coho oscillators, other imperfections of the radar and signal processor, and the finite signal duration.
- Clutter PSD is represented by a Gaussian function



Clutter attenuation

- Clutter attenuation of single delay line canceller

$$\mathrm{CA} \approx \frac{f_p^2}{4\pi^2\sigma_c^2} = \frac{f_p^2\lambda^2}{16\pi^2\sigma_v^2}$$

- Clutter attenuation of double delay line canceller

$$\mathrm{CA} \approx \frac{f_p^4}{48\pi^4\sigma_c^4} = \frac{f_p^4\lambda^4}{768\pi^4\sigma_v^4}$$

- Less of the clutter spectrum is included within the frequency response hence attenuates more of the clutter

MTI Improvement factor

- It is defined as “The signal to clutter ratio at the output of the clutter filter divided by the signal to clutter ratio at the input of the clutter filter, averaged uniformly over all target radial velocities of interest”

$$\text{improvement factor} = I_f = \left.\frac{(\text{signal/clutter})_{\text{out}}}{(\text{signal/clutter})_{\text{in}}}\right|_{f_d} = \left.\frac{C_{\text{in}}}{C_{\text{out}}} \times \frac{S_{\text{out}}}{S_{\text{in}}}\right|_{f_d}$$

$$= \text{CA} \times \text{average gain}$$

- Average gain of single delay line canceler is 2 and double delay line canceler is 6.

MTI Improvement factor

- Improvement factor of single and double delay line canceller

$$I_f(\text{single DLC}) \approx \frac{1}{2\pi^2(\sigma_c/f_p)^2} = \frac{\lambda^2}{8\pi^2(\sigma_v/f_p)^2}$$

$$I_f(\text{double DLC}) \approx \frac{1}{8\pi^4(\sigma_c/f_p)^4} = \frac{\lambda^4}{128\pi^4(\sigma_v/f_p)^4}$$

- For n cascaded delay line canceller

$$I_f\ (n \text{ cascaded DLCs}) \approx \frac{2^n}{n!}\left(\frac{1}{2\pi(\sigma_c/f_p)}\right)^{2n}$$

N-Pulse canceler

- To obtain $\sin^2(\pi f T_p)$ response weights of three pulses are 1,-2,1.
- For four pulse width weights are 1,-3,3,-1

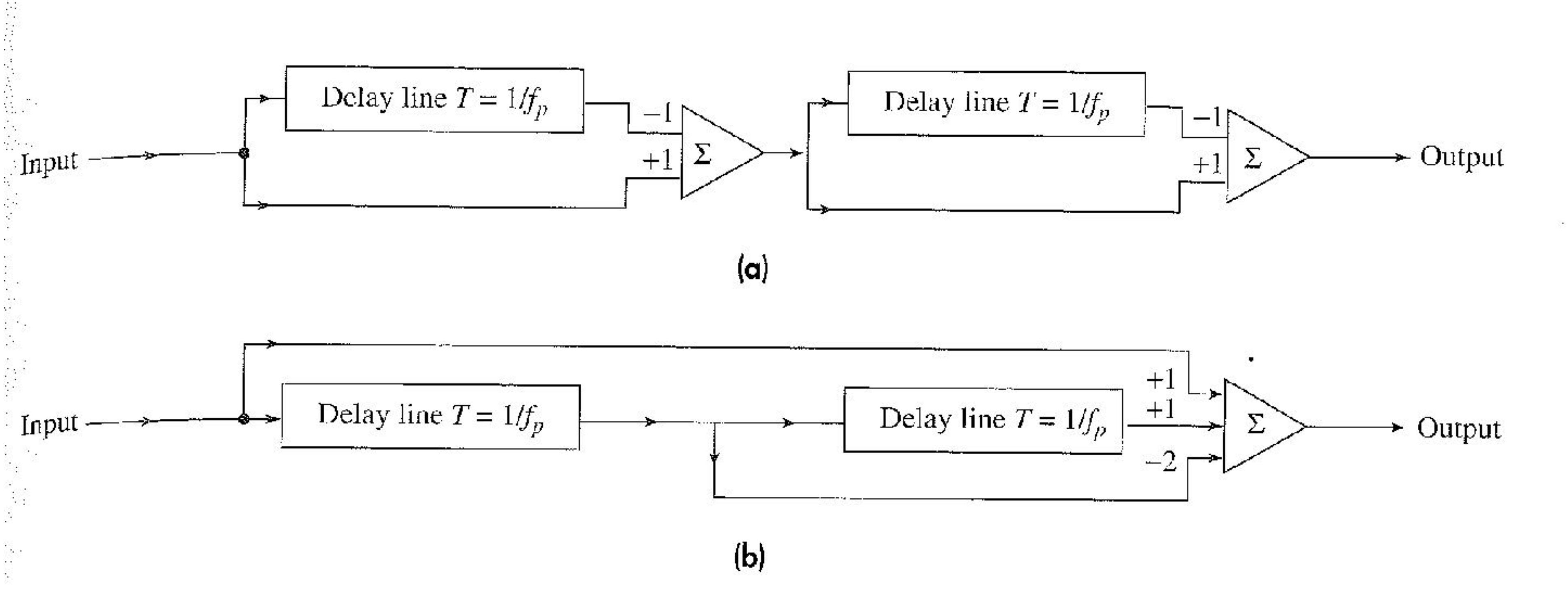


Figure 3.11 (a) Double delay-line canceler; (b) three-pulse canceler. The two configurations have the same frequency response. The three-pulse canceler of (b) is an example of a transversal filter.

Reference

- *Merrill I. Skolnik," Introduction to Radar Systems", 3rd Edition Tata Mc Graw-Hill 2008*

Unit II -
MTI And Pulse Doppler Radar

S-3 Doppler Filter Banks and Digital MTI Processing

S4- *Block Diagram of Digital MTI Doppler Signal Processor and Moving Target Detector - Limitations to MTI Performance*

Doppler Filter Banks

Doppler Filter Banks

- It is a set of contiguous filters for detecting targets. Advantages over single filters are

1) Multiple moving targets (including clutter) can be separated from one another.
2) A measure of the target's radial velocity can be obtained. (change of prf can resolve range ambiguities)
3) The narrowband Doppler filters exclude more noise than do the MTI delay line cancelers and provide coherent integration . Gain also high for larger 'n' pulses.

- This is achieved at the cost of greater complexity, difficult to achieve low side lobes to reduce clutter and need for significant no. of pulses to produce desirable filter characteristics.

Doppler Filter Banks

Doppler Filter Banks

- Employ the transversal filters with complex weights rather than real weights (amplitude) . Complex weights included phase shift as well as amplitude weights.
- The weights for each of N taps, with k outputs at each tap can be expressed as

$$w_{i,k} = e^{j[2\pi(i-1)k/N]}$$

Where i=1,2,..N and K is an index from 0 to N-1.

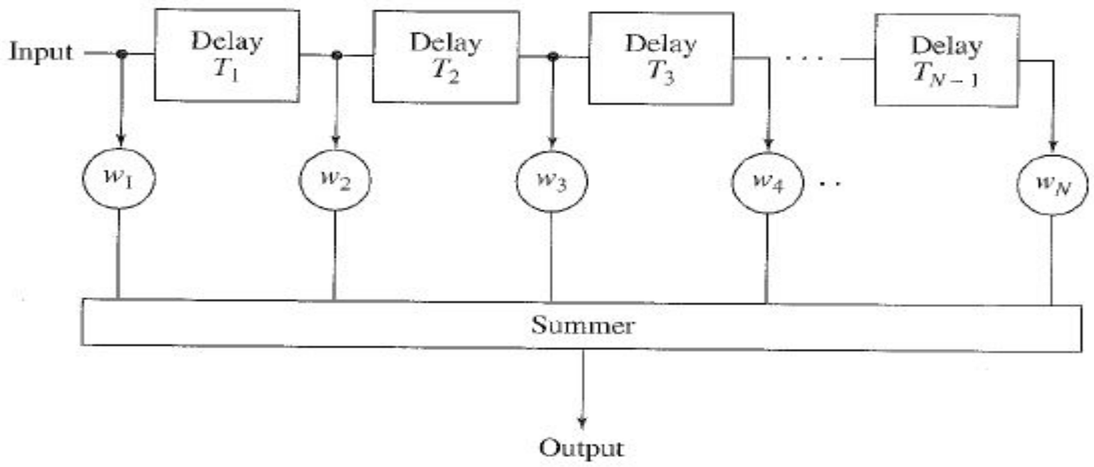


Figure 3.12 Transversal, or nonrecursive, filter for MTI signal processing.

Doppler Filter Banks

- The amplitude is the same at the each tap, only the phases are different (0,45,90,135,180,225,270 and 315 degrees)
- The magnitude of the frequency response function is the amplitude passband characteristics of the filter which is

$$|H_k(f)| = \left|\sum_{i=1}^{N} e^{-j2\pi(i-1)[fT - k/N]}\right| = \left|\frac{\sin[\pi N(fT - k/N)]}{\sin[\pi(fT - k/N)]}\right|$$

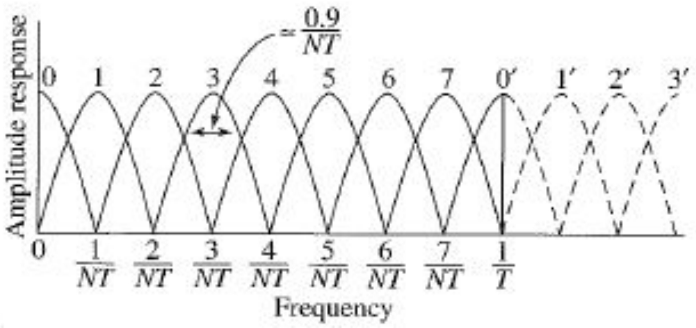
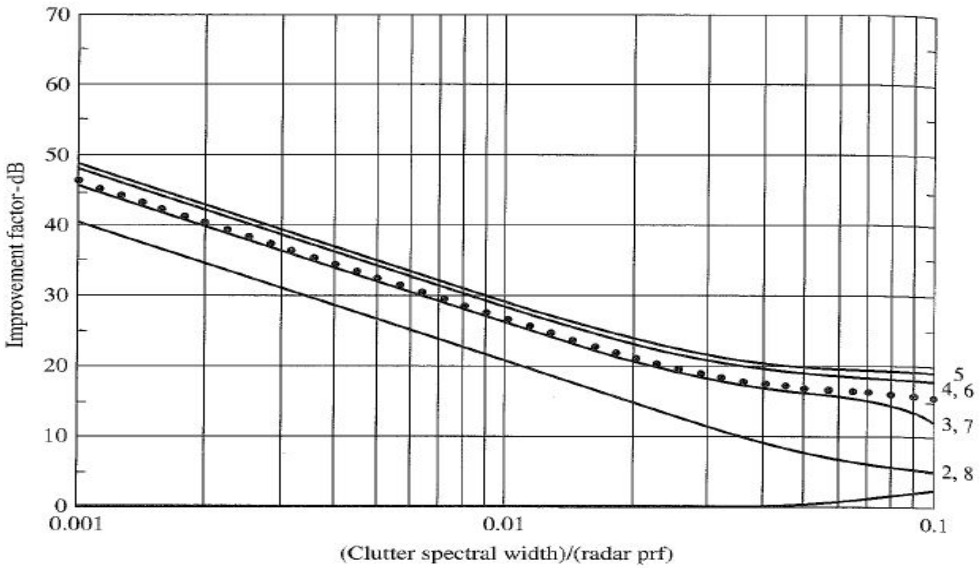


Figure 3.24 MTI doppler filter bank resulting from the processing of $N = 8$ pulses with the phase weights of Eq. (3.31), yielding the response of Eq. (3.34). N is the number of pulses processed and the number of filters generated; T is the pulse repetition period. The sidelobe structure of the filters is not shown.

Doppler Filter Banks

- Width of the main response is defined by spacing between the first pair of zeros is 2/NT.
- The half power width is approx. 0.9/NT.
- Transversal filter requires a total of (N-1)^2 digital multiplications.
- 8-Filter bank vs Uniform amp. Weight   (two pulse canceler)



Doppler Filter Banks -Limitations

- Sidelobes can be reduced by employing amplitude weights in addition to phase weights.
- Chebyshev filter and Dolph-Chebyshev array antenna pattern synthesis can be used to reduce side lobes

Limitations:

- More complex and Requires more pulses for good performances.
- Requires larger SNR if the true radial velocity is to be extracted when two or more prfs employed
- **Straddling loss:** Reduction in SNR at the crossover of adjacent filters , relative to the peak response at the center of the filter.

Digital MTI Processing

Advatntages

- Compensation for **blind phases** which causes a loss due to the difference in phase between the echo signal and the MTI ref. signal
- Greater dynamic range can be obtained than was possible with acoustic delay lines
- Unwanted changes in delay times due to temperature changes are eliminated
- No constraints in making the delay line in the digital memory synchronous with radar's prf.
- Digital processors can be made reprogrammable (obtained with many different filter characteristics)
- Digital MTI is more stable and reliable than analog MTI and requires less adjustments during operation in the field.

Blind phases

- Doppler shifted signal is not sampled at positive and negative values of sine wave with single phase detector and single processing channel.
- When the phase between the Doppler signal and the sampling at the prf results in a loss it is called a **blind phase**. (Blind speed-Sampling pulse appears at the same point in the Doppler cycle at each sampling time.

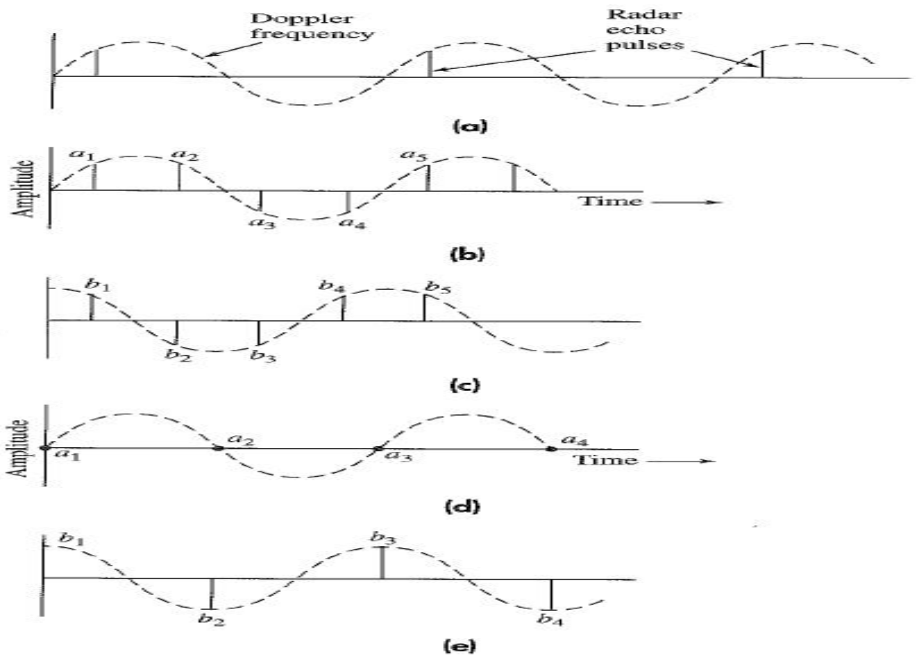
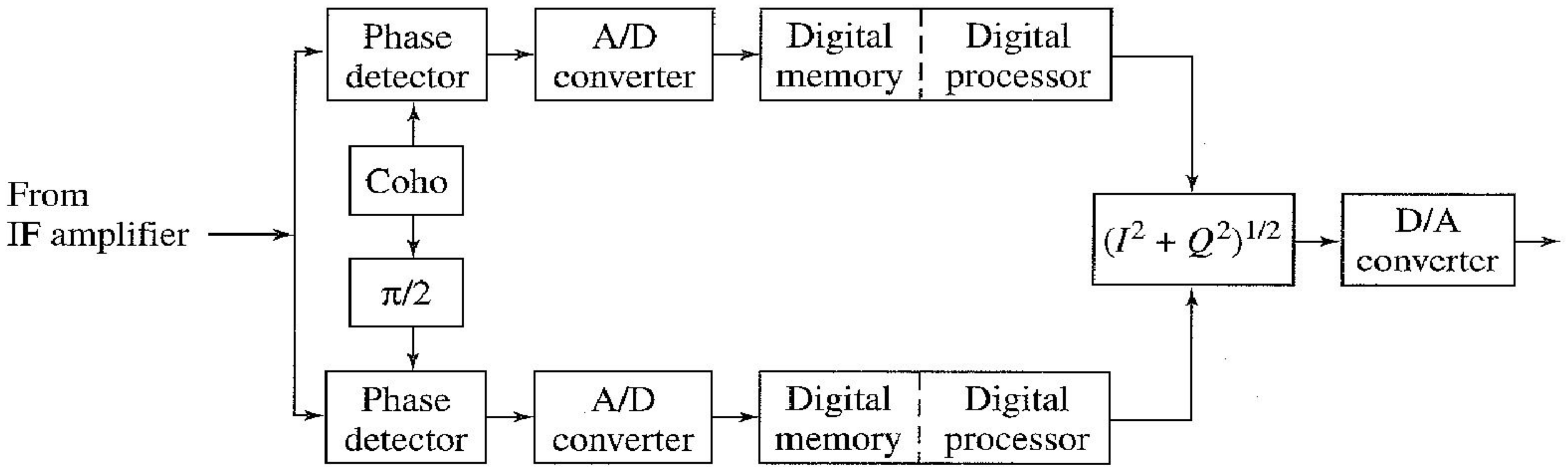


Figure 3.28 (a) Example of a blind speed in an MTI radar. The target's doppler frequency is equal to the prf. (b) Example of the effect of a blind phase in the *I* channel, and (c) in the *Q* channel. (d) The *I* channel of another special example of a blind speed. The prf is twice the doppler frequency and the phase of the sampling is such that there is no response at all since the sampling is at the zeros of the doppler frequency. Nothing is detected. (e) The *Q* channel for the example of (d) in which the sampling is at the positive and negative peaks of the doppler frequency so that there is complete recovery of the signal.

Block Diagram of Digital MTI Doppler Signal Processor

Doppler Filter Banks

- Doppler signal of I channel is represented as $A_d\sin(2\pi f_d t+\varphi_o)$ and Q channel is represented as $A_d\cos(2\pi f_d t+\varphi_o)$
- Sampling is achieved at one half of nyquist rate(Nyquist rate-Twice the signal BW)
- No. of Quantitation level in A/D is given as 2^N



Digital MTI Doppler Signal Processor -Limitations

- The output of the IF amplifier is usually made to limit at a level consistent with the MTI improvement factor and the full scale range of the A/D converter.
- The IF portion of the receiver is then a linear limiting amplifier
- The signal should not be allowed to exceed the full range of the A/D converter since the output would then be degraded and severe harmonics generated.

Limitation on the Improvement factor due to the A/D converter

- Since RMS value of the noise accompanying the signal is usually greater than the quantization step of the A/D converter, the digital word can change slightly from pulse to pulse in a noise like manner.

Shrader and Gregers-Hansen[36] give the limitation to the improvement factor due to quantization noise as

$$I_q = 20 \log [(2^N - 1)\sqrt{0.75}] \qquad \text{(dB)} \tag{3.35}$$

where N = number of bits. This is approximately 6 dB per bit. (Each bit represents a factor of two in amplitude resolution.) Thus a 10-bit A/D theoretically limits the improvement factor to about 60 dB. In practice, the A/D converter generally requires one or more additional bits to achieve the desired performance.

Digital MTI Doppler Signal Processor -Limitations

Dynamic Range

- Dynamic range is the maximum SNR that can be handled by an A/D converter without saturation.
- The noise level relative to the quantization step affects the dynamic range.
- The available dynamic range (Power ratio) is given by

$$\text{dynamic range} = 2^{2N-3}/k^2$$

Where N-no. of bits in A/D converter (included sign bit), k= rms noise level divided by the quantization level (k=2 value recommended by shrader and gregers-Hansen)

MOVING TARGET DETECTOR

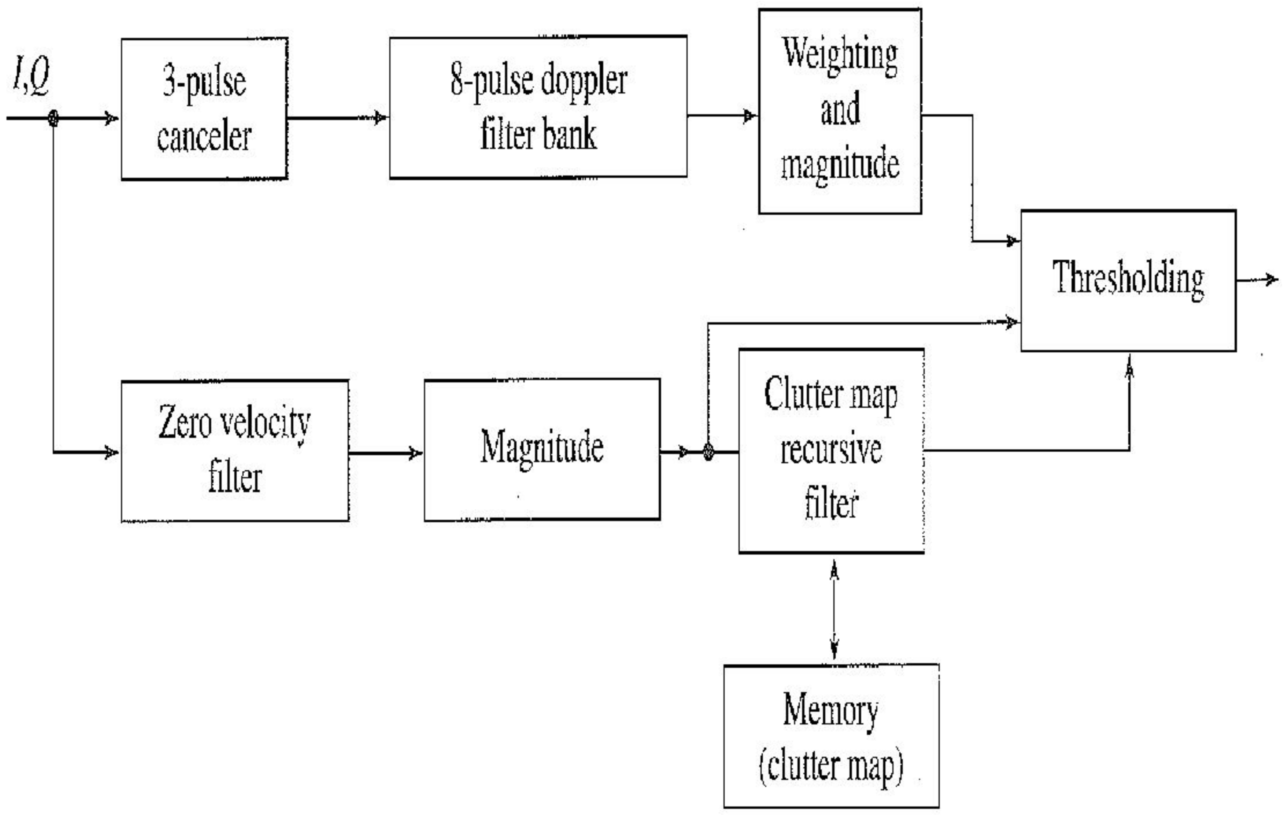
Other limitations

Errors and reduced performance can be due to

1. Other than a 90 deg phase difference between the I and Q ref. signals.
2. Gain and phase imbalance in the two channels
3. Timing jitter in the sample and hold circuits
4. Non linearity in the A/D and
5. Range straddling loss due to the sampling not being at the peak of the output of the matched filter

- Down conversion can be implemented to match I,Q channels phase, amp & freq.

MOVING TARGET DETECTOR Signal Processor



- An *eight-pulse FFT digital filter bank* with eight filters, preceded by a three-pulse delay-line canceler. The three-pulse canceler reduced the dynamic range of the signals which the doppler filter bank had to handle, and it compensated for the lack of adequate cancellation of stationary clutter in the doppler filters. The doppler filter bank separated moving targets from moving weather clutter if they appeared in different doppler filters.
- *Frequency-domain weighting* to reduce the doppler-filter sidelobes for better clutter attenuation.
- *Alternate prfs* to eliminate blind speeds and to unmask aircraft echoes from weather clutter.
- *Adaptive thresholds* to take advantage of the nonuniform nature of clutter.
- *Clutter map* to detect crossing targets with zero radial velocity that would otherwise be canceled by an ordinary MTI.
- *Centroiding* of multiple reports from the same target for more accurate location measurements.

Second Generation MTD

- The filter bank was implemented as a *generalized transversal (FIR) filter* rather than as an FFT so as to provide more flexibility in design and reduce the doppler-filter sidelobes.
- A *two-pulse delay-line canceler* (rather than the three-pulse canceler of the original) preceded the filter bank.
- The *zero radial-velocity filter* was also designed as a transversal filter. It utilized the Chebyshev criterion to produce relatively uniform filter gain across the portion of the doppler space not covered by the nonzero-doppler filters.
- The *clutter map* had one cell for each range-azimuth cell rather than one cell for each range-CPI.
- The *nonzero-doppler filters* were based on the method of DeLong and Hoffstetter (mentioned in ref. 53). They provided sidelobe levels 10 dB lower than the original MTD, and thus gave better performance in rain. When the two-pulse delay line preceded the filter bank, the number of bits required in the transversal filter decreased, so that the filter weights only had to be 3 or 4 bits plus sign.

Third Generation MTD

- Twelve bit filter weights were used instead of 5 bit weights of the Lincoln MTD

- The range and azimuth resolutions of this radar were improved compared to the original MTD.

Limitations to MTI Performance

1) Antenna scanning modulation

- If the clutter scatterers were perfectly stationary and there were no instabilities in the radar equipment, there would be still finite spectral spread due to the finite duration of echo signal. This limitation has been called antenna scaling modulation.

- This is due to finite time on target. The longer the time on target, the less will be the spread in the clutter spectrum.

- The pulse to pulse difference in echo amplitude due to the antenna pattern shape also contributes to the clutter residue that is part of the antenna scanning modulation.

Limitations to MTI Performance

2) Internal fluctuations of clutter

-Echoes from mountains, rocks, buildings, fences can be considered stationary.

- Clutter echoes including sea, rain and chaff, trees , large vegetation and structures blowing in the wind can be in motion.

- The amplitude and phase fluctuations of windblown trees and vegetation can result in widened frequency spectrum of the clutter echo.

-Compared Gaussian model (Power law model) , exponential model could adequately represent measured clutter spectra over a wide dynamic range down to 80 dB below the peak.

Limitations to MTI Performance

3) Equipment instabilities – results in uncancelled clutter echoes cause a limit to the improvement factor

- amplitude change – The clutter attenation for a single delay line canceller is $\dfrac{V_m^2}{2\sigma_v^2}$.

Where Vm –voltage variation of each of the two pulses about the mean value.

- Phase changes

Phase Changes If the echo received from the first pulse from stationary clutter is represented as $A \sin(\omega t + \phi)$, and if the echo from the second pulse is $A \sin(\omega t + \phi + \Delta\phi)$, there will be an uncanceled residue from a single delay-line canceler equal to the difference, $2A \sin(\Delta\phi/2)$, where $\Delta\phi$ is the phase change between pulses. For small phase changes, the output voltage is $A\Delta\phi$. The clutter attenuation is then $(1/\Delta\phi)^2$ and the improvement factor is twice this.

Limitations to MTI Performance

- Phase noise

  Phase Noise Noise due to phase fluctuations associated with the stalo and coho oscillators can be a major limitation to the improvement factor of high-performance MTI radars. Generally, phase noise has a much larger effect than noise caused by amplitude instabilities. The phase noise from oscillators in the exciter of a power amplifier affect the transmitted signal as well as the signal in the receiver. The spectrum of a CW oscillator is not

- Phase noise decreases as the frequency increases from the carrier and then levels off to a constant value when thermal noise dominates.
- The shape of the noise spectrum is influenced by Q of the resonator. Sometimes there are discrete frequency spikes appearing in spectrum called as spurious or spurs are often associated with power supply or mechanical vibrations.
- Phase noise can be introduced by mixers, high power amplifier .
- Phase noise of an oscillator can be reduced by super conductive resonators to increase its Q.

Limitations to MTI Performance

4) Limiting

- Limiter should be set above receiver noise by an amount equal to the improvement factor

Reference

- *Merrill I. Skolnik," Introduction to Radar Systems", 3rd Edition Tata Mc Graw-Hill 2008*

Unit II -
MTI And Pulse Doppler Radar

S-5 *Pulse Doppler Radar*

High, Medium and Low prf Doppler

S-6 *Other Doppler Radar Topics and Tracking with Radar*

Pulse Doppler Radar

- A pulse radar that extracts the Doppler frequency shift for the purpose of detecting moving targets in the presence of clutter- MTI or pulse Doppler radar.
- In a sampled measurement system like a pulse radar ,ambiguities can arise in both the Doppler frequency(relative velocity) and range(time delay) measurements.
- Range ambiguities are avoided with a low sampling rate(low pulse PRF) and Doppler frequency ambiguities are avoided with a high sampling rate.
- In most radar applications the sampling rate or PRF cannot be selected to avoid both types of measurement ambiguities. Therefore a compromise must be made and this decides if radar is pulse Doppler or MTI.

PULSE DOPPLER RADAR

- A radar that increases its PRF high enough to avoid the problems of blind speeds is called a pulse Doppler radar.
- Three different types of pulse radars that use Doppler -

1. The *MTI* with no range ambiguities and many doppler ambiguities.
2. The *high-prf pulse doppler* with just the opposite: many range ambiguities and no doppler ambiguities.
3. The *medium-prf pulse doppler radar* with some of each.

Classes of PULSE DOPPLER RADARS

	Range Measurement	Doppler Measurement
Low PRF	Unambiguous	Highly Ambiguous
Medium PRF	Ambiguous	Ambiguous
High PRF	Highly Ambiguous	Unambiguous

- Slides taken from Dr. Robert M. O'Donnell

PULSE DOPPLER PRFs

Frequency	PRF Type	PRF Range*	Duty Cycle*
• X- Band	High PRF	100 - 300 KHz	< 50%
• X- Band	Medium PRF	10 - 30 KHz	~ 5%
• X- Band	Low PRF	1 - 3 KHz	~.5%
• UHF	Low PRF	300 Hz	Low

* Typical values only; specific radars may vary inside and outside these limits

- Slides taken from Dr. Robert M. O’Donnell

High PRF Mode

Frequency	PRF Type	PRF Range*	Duty Cycle*
• X- Band	High PRF	100 - 300 KHz	< 50%

Example: PRF = 150 KHz Duty Cycle = 35%

PRI= 6.67 μsec Pulsewidth = 2.33 μsec

Unambiguous Range = 1 km

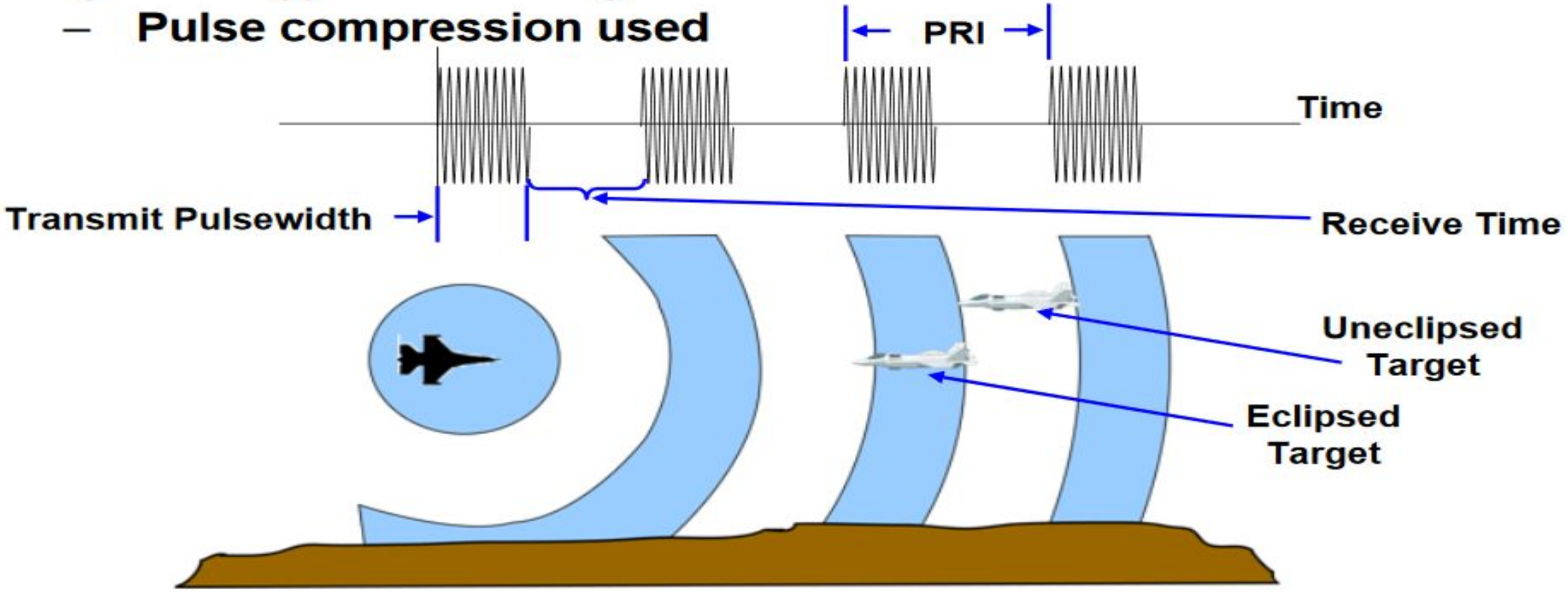
Unambiguous Doppler Velocity = 4,500 knots

- For high PRF mode :
  - Range – Highly ambiguous
    - Range ambiguities resolved using techniques discussed in Lecture 13
  - Doppler velocity – Unambiguous
    - For nose on encounters, detection is clutter free
  - High duty cycle implies significant "Eclipsing Loss"
    - Multiple PRFs, or other techniques required

- Slides taken from Dr. Robert M. O'Donnell

HIGH PRF mode - Range Eclipsing

- High PRF airborne radars tend to have a **High Duty** cycle to get high energy on the target
  - Pulse compression used



- Eclipsing loss is caused because the receiver cannot be receiving target echoes when the radar is transmitting
  - Can be significant for high duty cycle radars
  - Loss can easily be 1-2 dB, if not mitigated

- Slides taken from Dr. Robert M. O'Donnell

High PRF Pulse Doppler Radar

- No Doppler velocity ambiguities, many range ambiguities
  - Significant range eclipsing loss
- Range ambiguities can be resolved by transmitting 3 redundant waveforms, each at a different PRF
  - Often only a single range gate is employed, but with a large Doppler filter bank
- The antenna side lobes must be very low to minimize side lobe clutter
  - Short range side lobe clutter often masks low radial velocity targets
- High closing speed aircraft are detected at long range in clutter free region
- Range accuracy and ability to resolve multiple targets can be poorer than with other waveforms

Slides taken from Dr. Robert M. O'Donnell

Medium PRF Mode

Frequency	PRF Type	PRF Range*	Duty Cycle*
• X- Band	Medium PRF	10 - 30 KHz	~ 5%

Example : 7 PRF = 5.75, 6.5, 7.25, 8, 8.75, 9.5 & 10.25 KHz

(From Figure 3.44 in text)

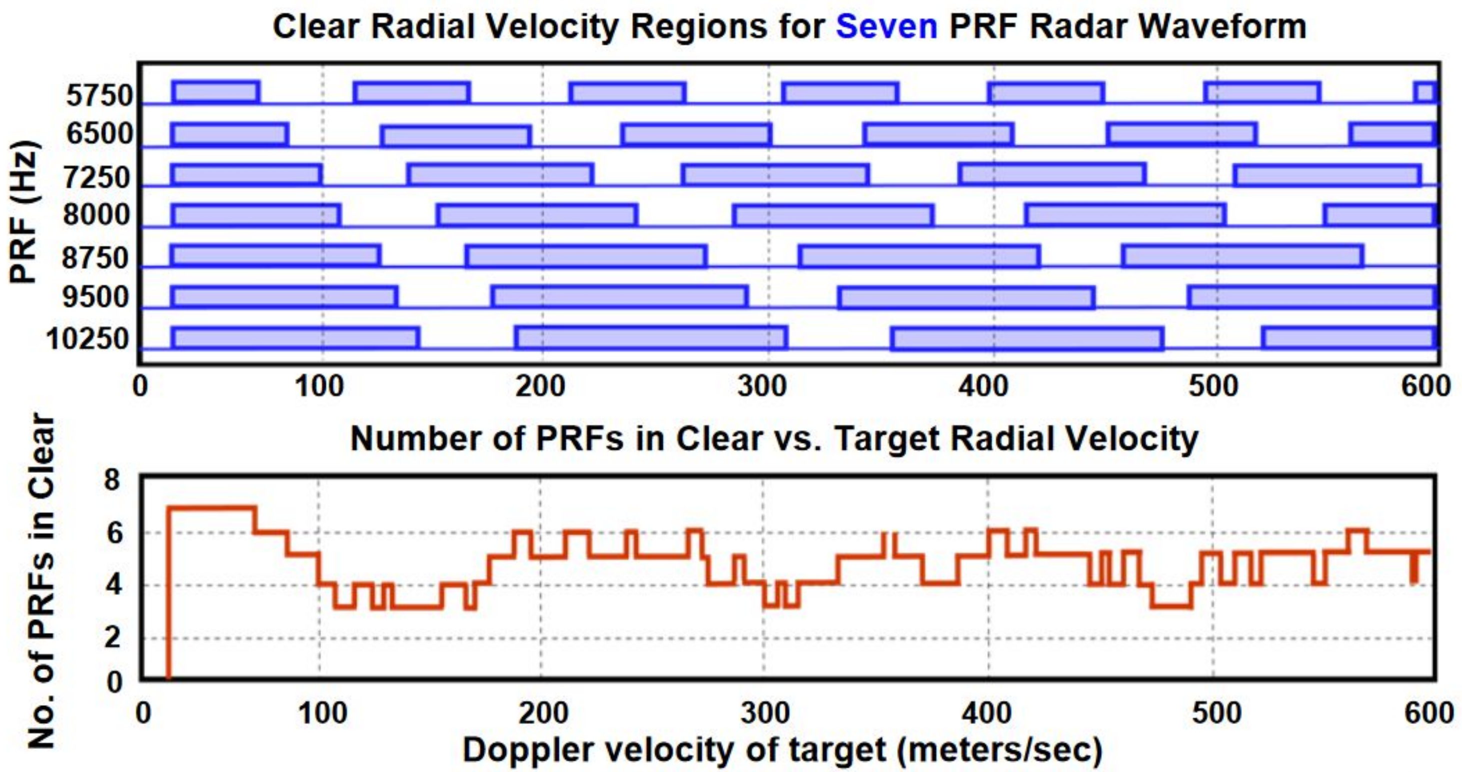
Range Ambiguities = ~14 to 26 km

Blind Speeds = ~175 to 310 knots

- For the medium PRF mode :
  - Clutter and target ambiguities in range and velocity
  - Clutter from antenna sidelobes is an significant issue

- Slides taken from Dr. Robert M. O'Donnell

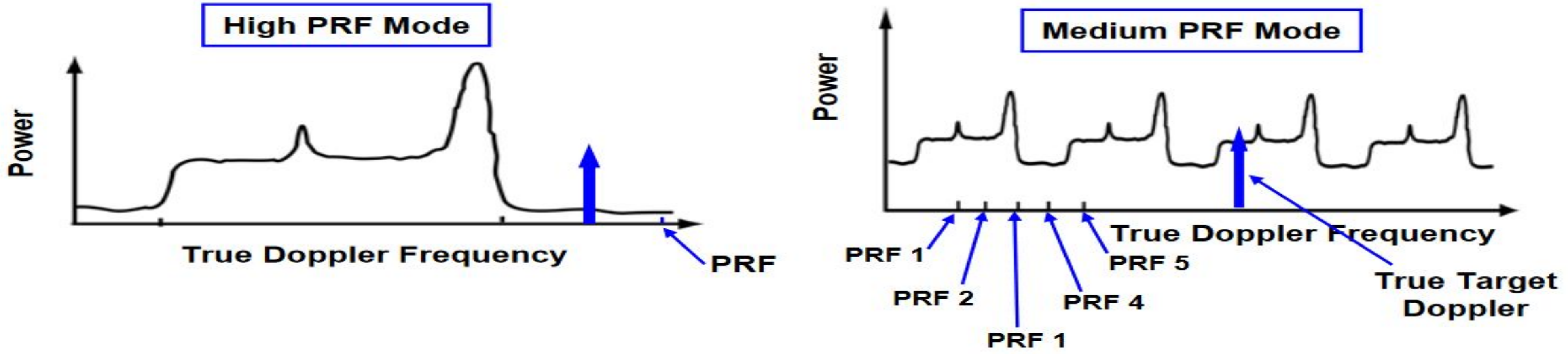
Clear Velocity Regions for a Medium PRF Radar



- The multiple PRFs (typically 7) and their associated higher radar power are required to obtain sufficient detections to unravel range and velocity ambiguities in medium PRF radars

- Slides taken from Dr. Robert M. O'Donnell

Medium PRF Mode



- In the Doppler domain, the target and clutter alias (fold down) into the range 0 to PRF1, PRF2, etc.
  - Because of the aliasing of sidelobe clutter, medium PRF radars should have very low sidelobes to mitigate this problem
- In the range domain similar aliasing occurs
  - Sensitivity Time Control (STC) cannot be used to reduce clutter effects (noted in earlier lectures)
- Range and Doppler ambiguity resolution techniques described in previous lecture

- Slides taken from Dr. Robert M. O'Donnell

Medium PRF Pulse Doppler Radar

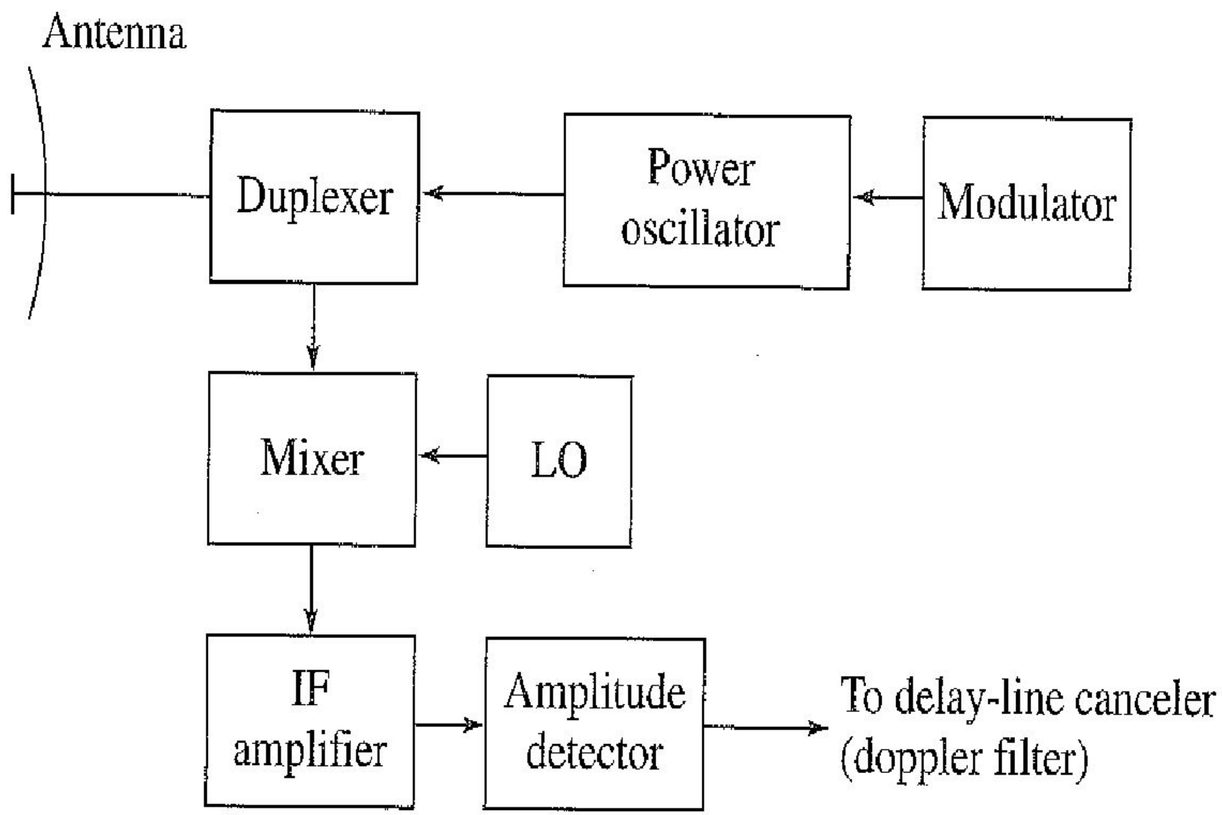
- Both range and Doppler ambiguities exist
  - Seven or eight different PRFs must be used
  - Insures target seen at enough Doppler frequencies to resolve range ambiguities
  - Transmitter larger because of redundant waveforms used to resolve ambiguities
- There is no clutter free region
  - Fewer range ambiguities implies less of a problem with sidelobe clutter
  - Antenna must have low side lobes to reduce side lobe clutter
- Often best single waveform for airborne fighter / interceptor
- More range gates than high PRF, but fewer Doppler filters for each range gate
- Better range accuracy and Doppler resolution than high PRF systems

Low PRF Doppler

- No range ambiguities, but many doppler ambiguities (blind speeds).
- Requires TACCAR and DPCA to remove effects of platform motion.
- Operates clutter free at long range where no clutter is seen due to curvature of the earth.
- Sidelobe clutter is usually not as important as it is in pulse doppler systems.
- Best employed at UHF or perhaps *L* band. Increased blind speeds and the lower effectiveness of platform motion compensation prevent its use at the higher microwave frequencies.
- The lower RF frequency (UHF) of the AMTI radar results in wider antenna beamwidths 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.
- For comparable performance the required product of average power and antenna aperture is less than for pulse doppler radars.
- Usually simpler than pulse doppler radars.
- Cost is generally much less than pulse doppler radars of comparable performance.
- AMTI cannot be used in fighter/interceptor *X*-band radars for look-down detection of targets in clutter. The low-prf mode without doppler processing, however, is used to advantage when there is no clutter present, as when the antenna is looking up or the target is at a range less than the height of the radar over the ground so that near-in ground clutter that enters via the sidelobes can be gated out.

Other Doppler radar Topics

Non coherent MTI Radar



- It uses the clutter echo signal as the reference signal to extract the Doppler shifted target echo
- Same as conventional radar except MTI filter which is usually a delay line canceller.
- It is nonlinear device and relatively simple.
- Used in land based and airborne MTI applications
- Delay line canceller must be switched out when no clutter present.
- Improvement factor is poorer compared to coherent MTI.
- Losses occurs due to blind phases also noisier.
- Not an attractive candidate for MTI applications that require large improvement factor.

Other Doppler radar Topics

Detection of ground moving targets:

- Airborne Radar Detection of Ground Moving Targets (AMTI)

    -Ground Moving Target Indication – uses low or medium prf

- Side Looking Airborne radar

    -high resolution radar

    - adaptive threshold is used (to reduce clutter spread spectrum)

    - It can extract slow moving targets down to 5 miles per hours at a range of 50nmi. 80 nmi range for faster and larger targets

- Synthetic Aperture Radar with MTI

    - Produces high resolution image by synthesizing in its processor.

    - resolution and cross range of one meter

    - more complex

    - moving targets can be detected if Doppler freq. Shift is greater than spectral bandwidth of the stationary ground clutter echo.

    - need high prf . Not able to detect targets woth low radial velocity

- Inferometric SAR

    - Uses phase information to detect moving targets

    -Employs to side looking antenna along the line of travel

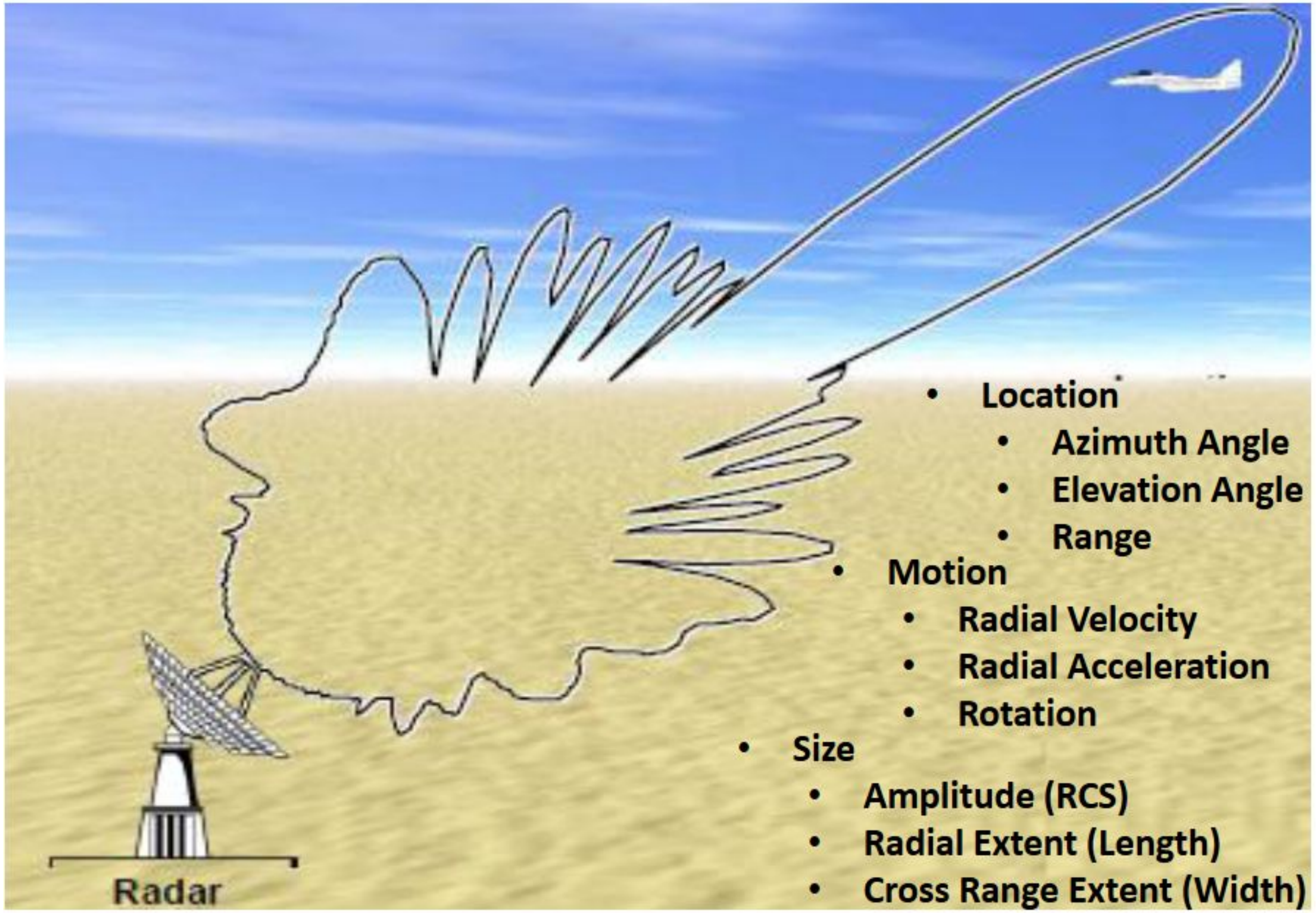
    - Applicatiion : Detection and measurement of radial velocity of ocean currents

Other Doppler radar Topics

- Pulse Burst Radar
- Single Pulse Doppler Radar
- Adaptive AMTI
- CW radar – Simple CW radar and FM CW radar

Tracking Radar

Tracking Functions and Parameter Estimation



Tracking Radar: Functions & Parameter Estimation

- A tracking radar has a pencil beam to receive echoes from target.
- A tracking-radar system
  - measures the coordinates (r,θ,ϕ) of a target
  - provides data(f_d, v_r) which used to determine the target path
  - predict its future position.
  - used to measure the trajectory of the moving target [Ex: missile] and to predict future position.
- Types:
  - STT Radar
  - MTT Radar
    - ADT
    - Phased Array Radar Tracking
    - TWS Radar

Tracking Radar

- STT [Single Target Tracker] Radar designed to
  - Continuously track a single target at a high data rate
  - Ex: Weapon control radar [guided missile targets]
- ADT[Automatic Detection and Track] Radar
  - Lower data rate
  - Ex: Air Surveillance Radar [Military and Civilian]
- Phased Array Radar
  - High data rate
  - Electronically steered phase array antenna
  - Used on time sharing basis
  - Ex: Air-defense weapon radar system [MOTR]
- TWS [Track while Scan] Radar
  - Moderate data rate
  - Ex: Aircraft Landing Radar (Airborne Radar)

Tracking Radar

TRADEX

ASR
Courtesy Lincoln Laboratory

MOTR
Courtesy of Lockheed Martin.

Tracking Radar

TRADEX MTT Radar System

Multl-Target Tracker (MTT), Target Resolution and Discrimination Experiment (TRADEX) is a

- high-power,
- high-sensitivity instrumentation radar system
- is unique because it utilizes a large, steered, pencil-beam antenna.
- designed to detect and track [≈> 63 targets] within the beam of the radar.

It provides data necessary for determining the angular locations and ranges of all of these targets, as well as signature data necessary for target identification.

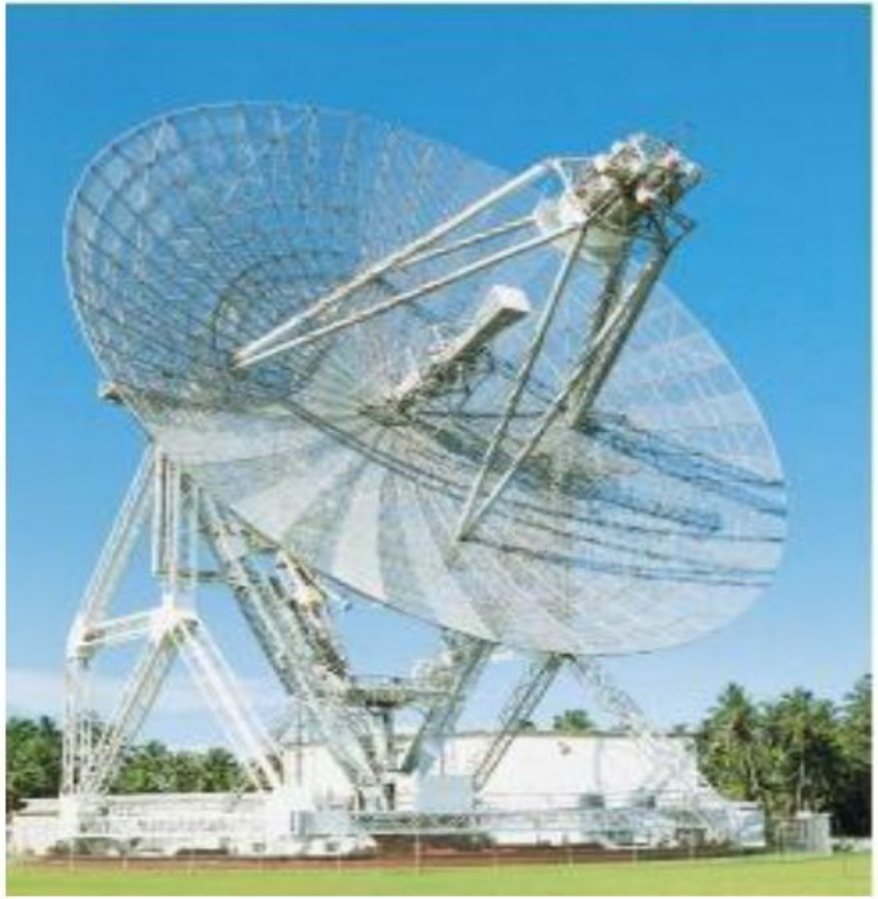
It automatically processes received signals, reports targets, initiates and maintains target track files, and presents target information to the radar operators through real-time interactive graphical displays.

Other Doppler radar Topics

C-band monopulse precision tracking radar [NASA Wallops Island Station]

It has a 29-ft-diameter antenna with capable of 0.01 mil tracking accuracy.

Other Doppler radar Topics

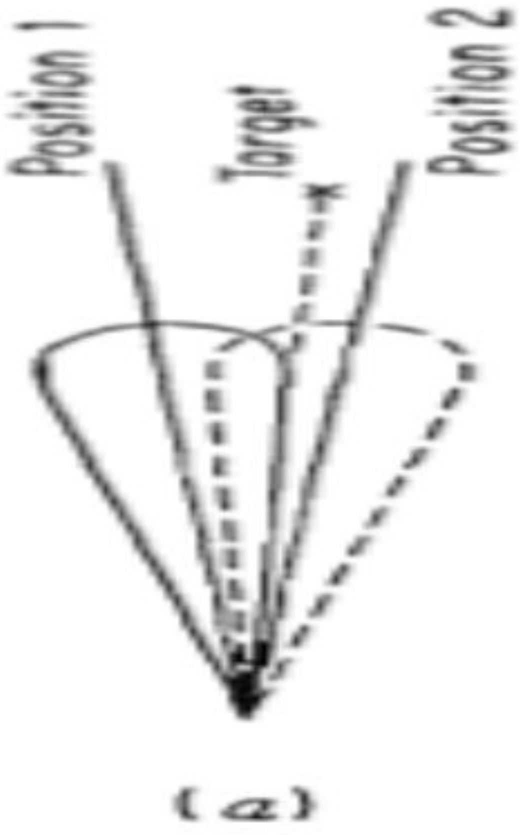


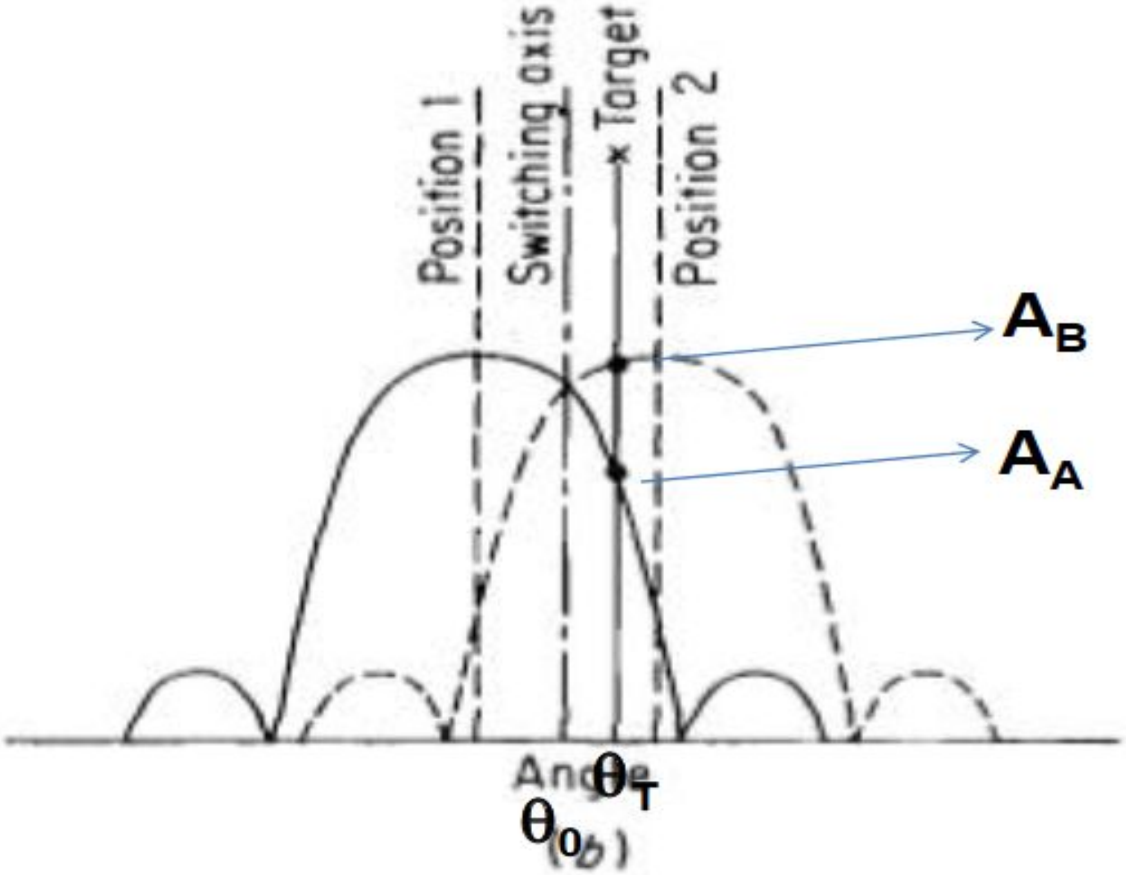
Operating frequency (deep-space mode)	UHF (422 MHz)
Dish	Steerable 150-ft dish
Beamwidth	1.1° (UHF)
Peak power output	5 MW
Average power output	120 kW
Pulse-repetition frequency	300 Hz
Pulse length	80 μsec
Signal-to-noise ratio (per pulse)	38 dB @ 1000 km (0-dBsm target)
Accuracy	
Range resolution	20 m
Range-rate resolution	15 mm/sec
Azimuth and elevation angle	0.03°

ARPA [Marshall Islands] Long-Range Tracking and Instrumentation Radar (ALTAIR)

Angle Tracking

- A tracking radar has a pencil beam to receive echoes from target.





Reference

- *Merrill I. Skolnik," Introduction to Radar Systems", 3rd Edition Tata Mc Graw-Hill 2008*
- Radar Systems Engineering Lecture "Airborne Pulse Doppler Radar" Dr. Robert M. O'Donnell IEEE New Hampshire SectionGuest Lecturer.
- https://www.iist.ac.in/sites/default/files/people/IN14204/Lecture%2028-32%20Tracking%20Radar.pdf

Unit II -
MTI And Pulse Doppler Radar

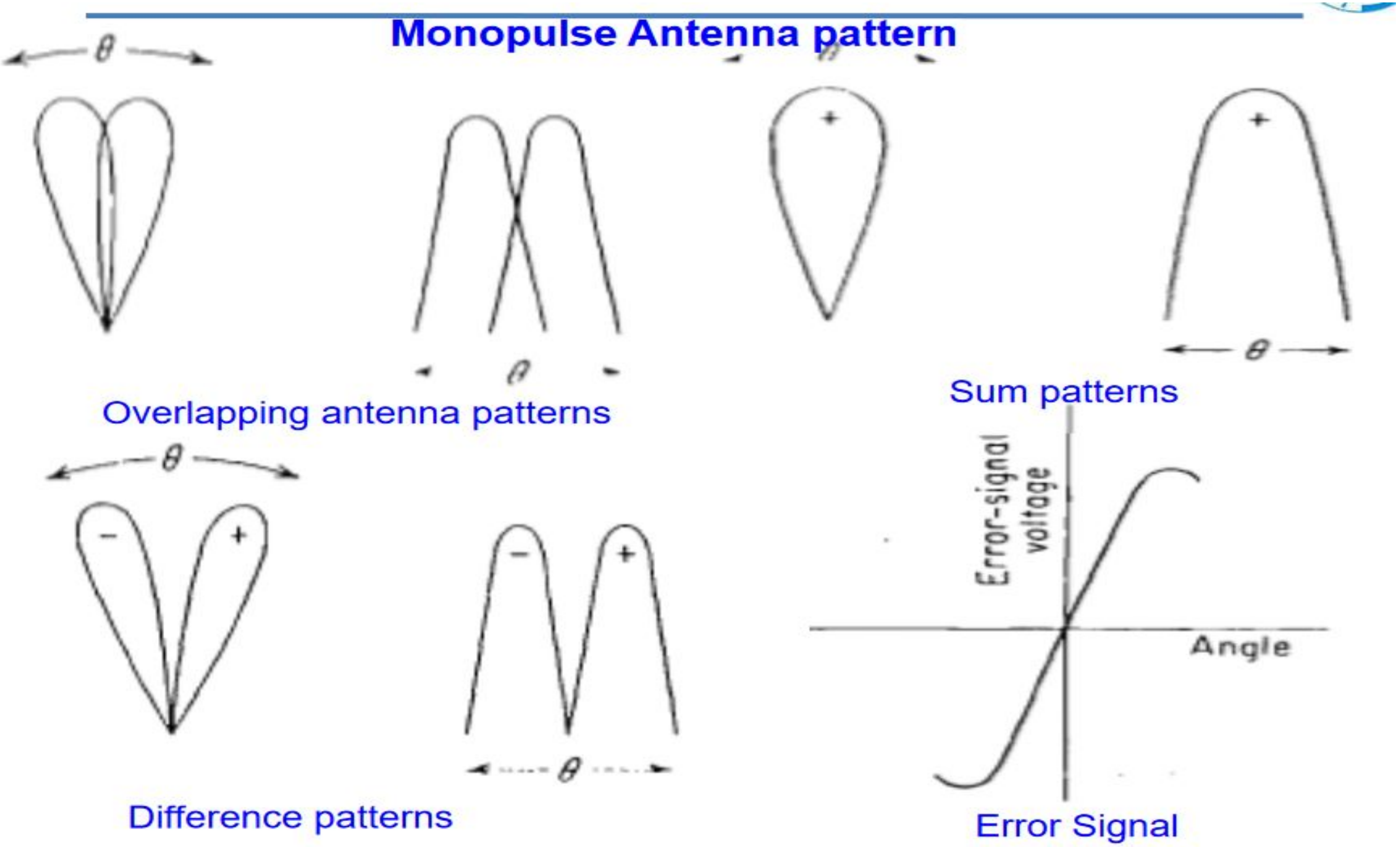
S-7 *Mono pulse Tracking , Two Coordinate amplitude comparison monopulse tracking*

S-8 *Conical Scan and Sequential Lobing , Limitations to Tracking Accuracy*

Tracking Radar

- Methods to extract error signal may be classified as
  - Sequential lobing
  - Conical scan
  - Simultaneous lobing or monopulse

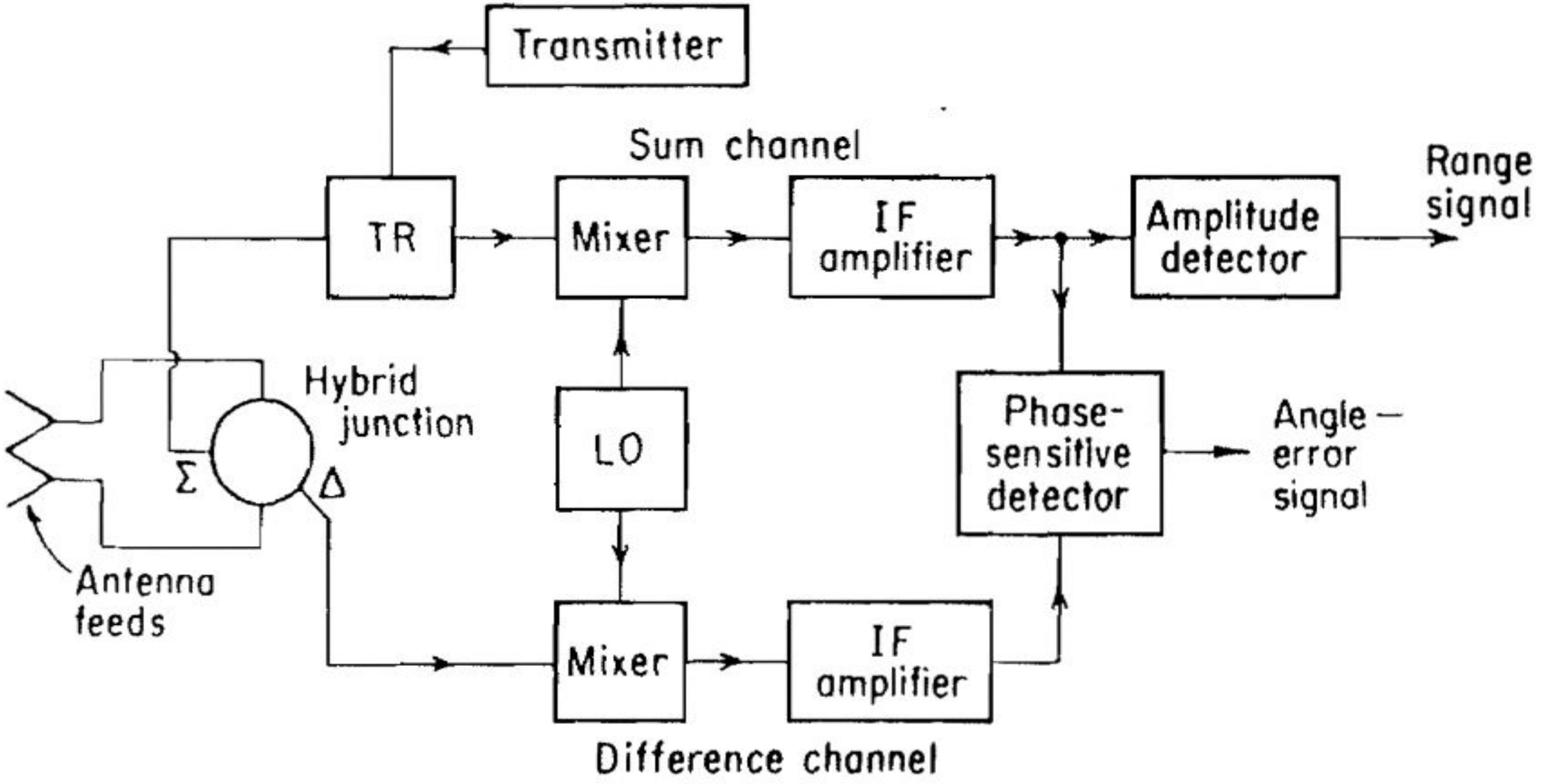
Mono pulse Radar



Mono Pulse Radar

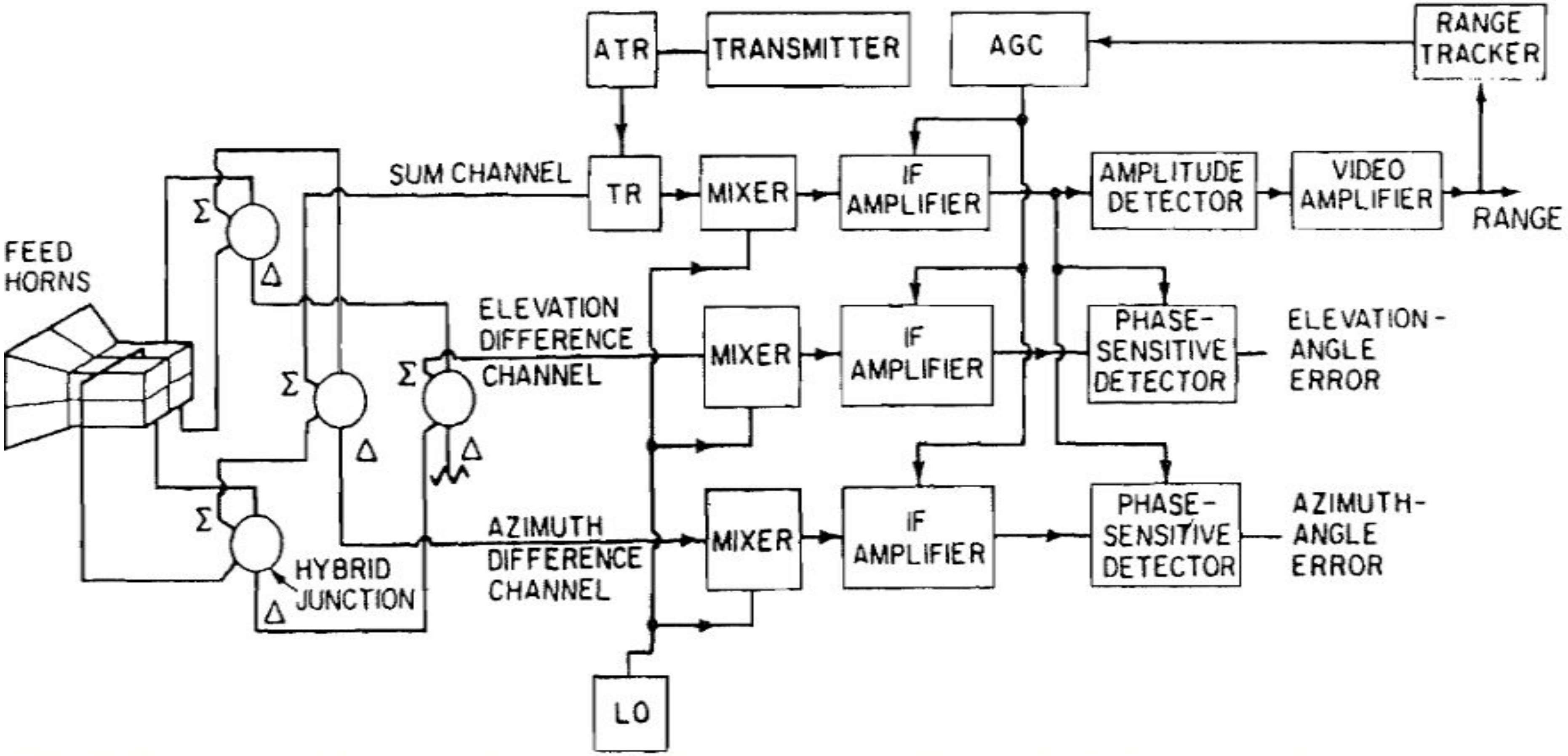
- Monopulse radar is a radar system that compares the received signal from a single radar pulse against itself in order to compare the signal as seen in multiple directions, polarizations, or other differences.
- In this technique,
  - The RF signals received from two offset antenna beams are combined so that both the sum and the difference signals are obtained simultaneously.
  - The sum and difference signals are multiplied in a phase-sensitive detector to obtain both the magnitude and the direction of the error signal.
  - To determine the angular error is obtained on the basis of a single pulse; hence the name monopulse is quite appropriate.

Amplitude-Comparison Monopulse radar (one coordinate)



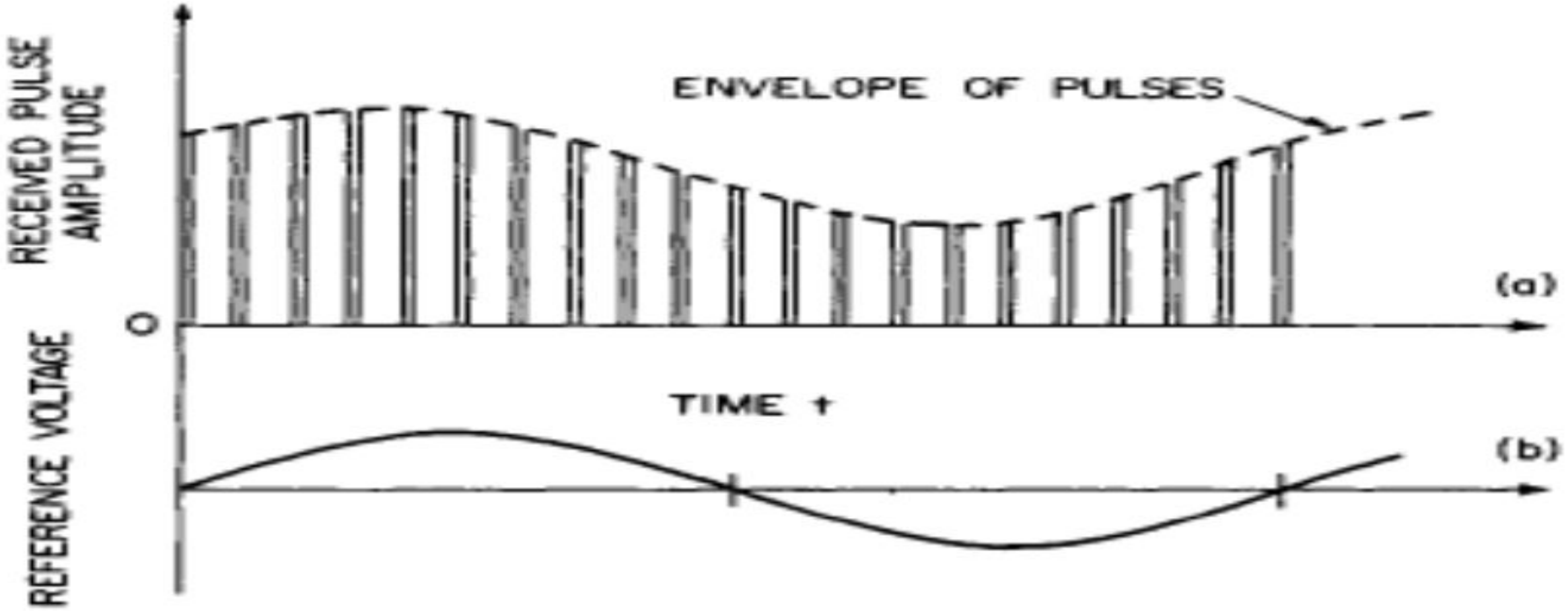
Block diagram of amplitude-comparison monopulse radar (one angular coordinate)

Amplitude-Comparison Monopulse radar (two coordinate)



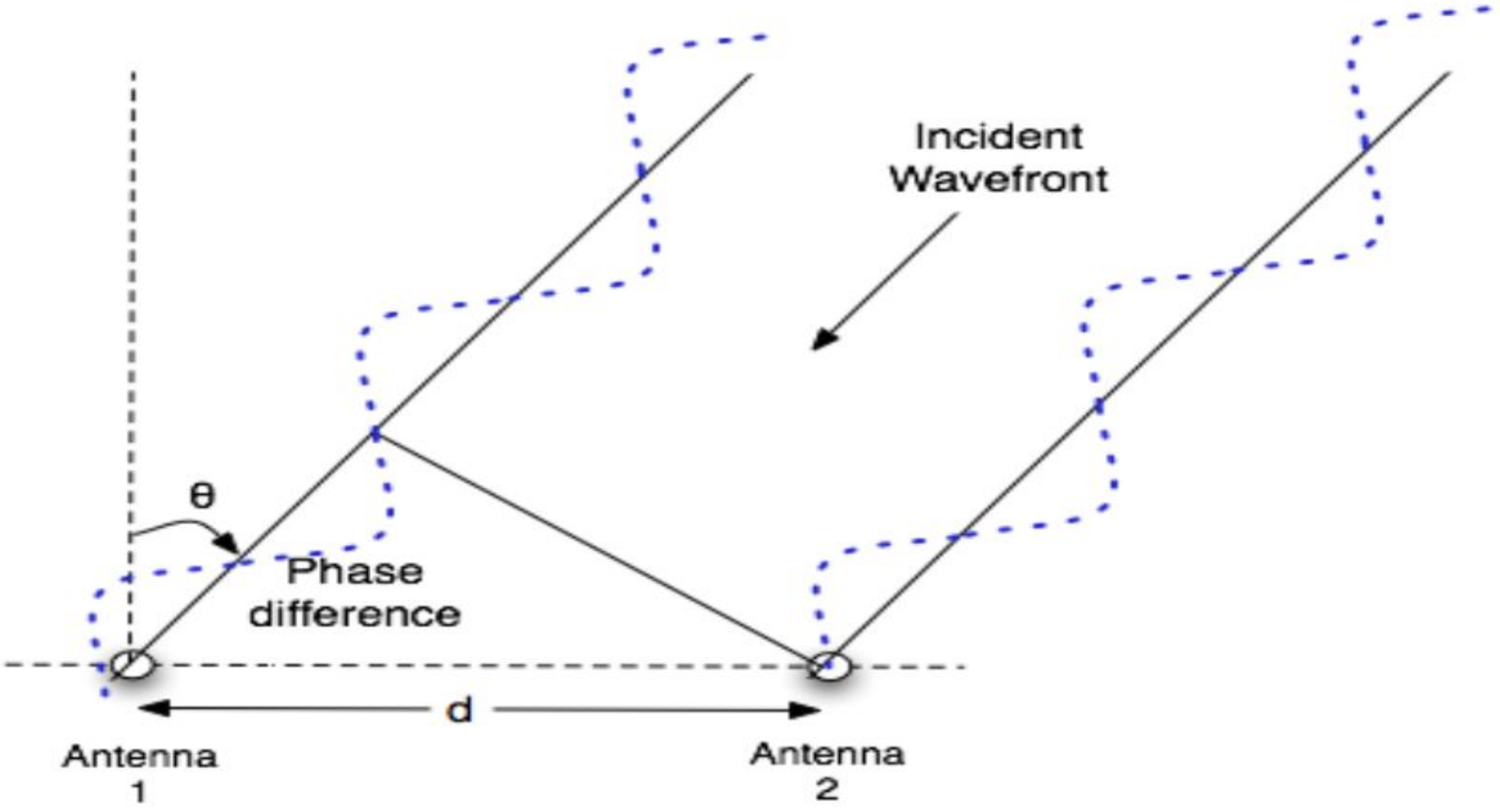
Block diagram of amplitude-comparison monopulse radar (Two angular coordinate)

Amplitude-Comparison Monopulse radar (two coordinate)

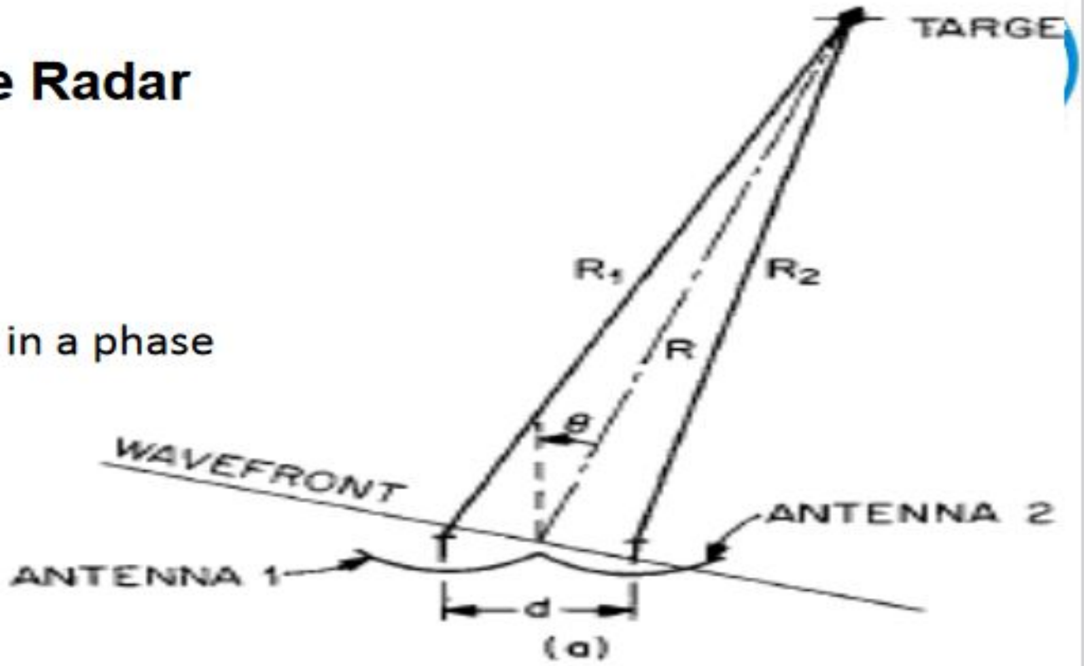


(a) Angle error information contained in the envelope of the received pulses in a conical-scan radar. (b) Reference signal derived from the drive of the conical-scan feed.

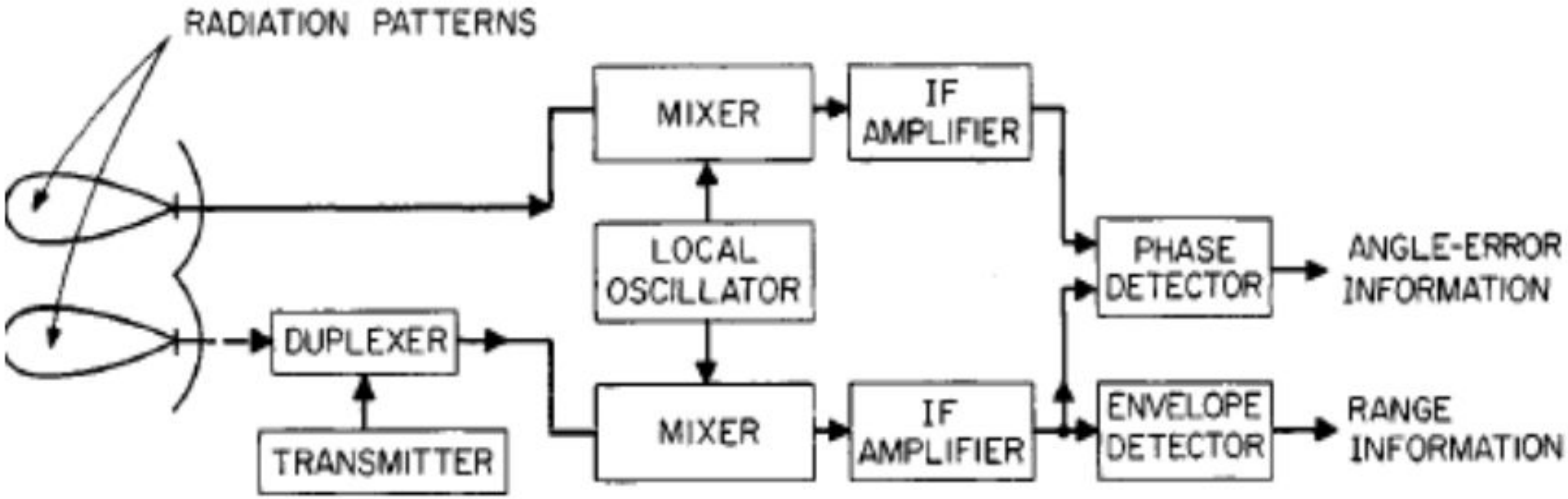
Phase-Comparison Monopulse Radar



Phase-Comparison Monopulse Radar

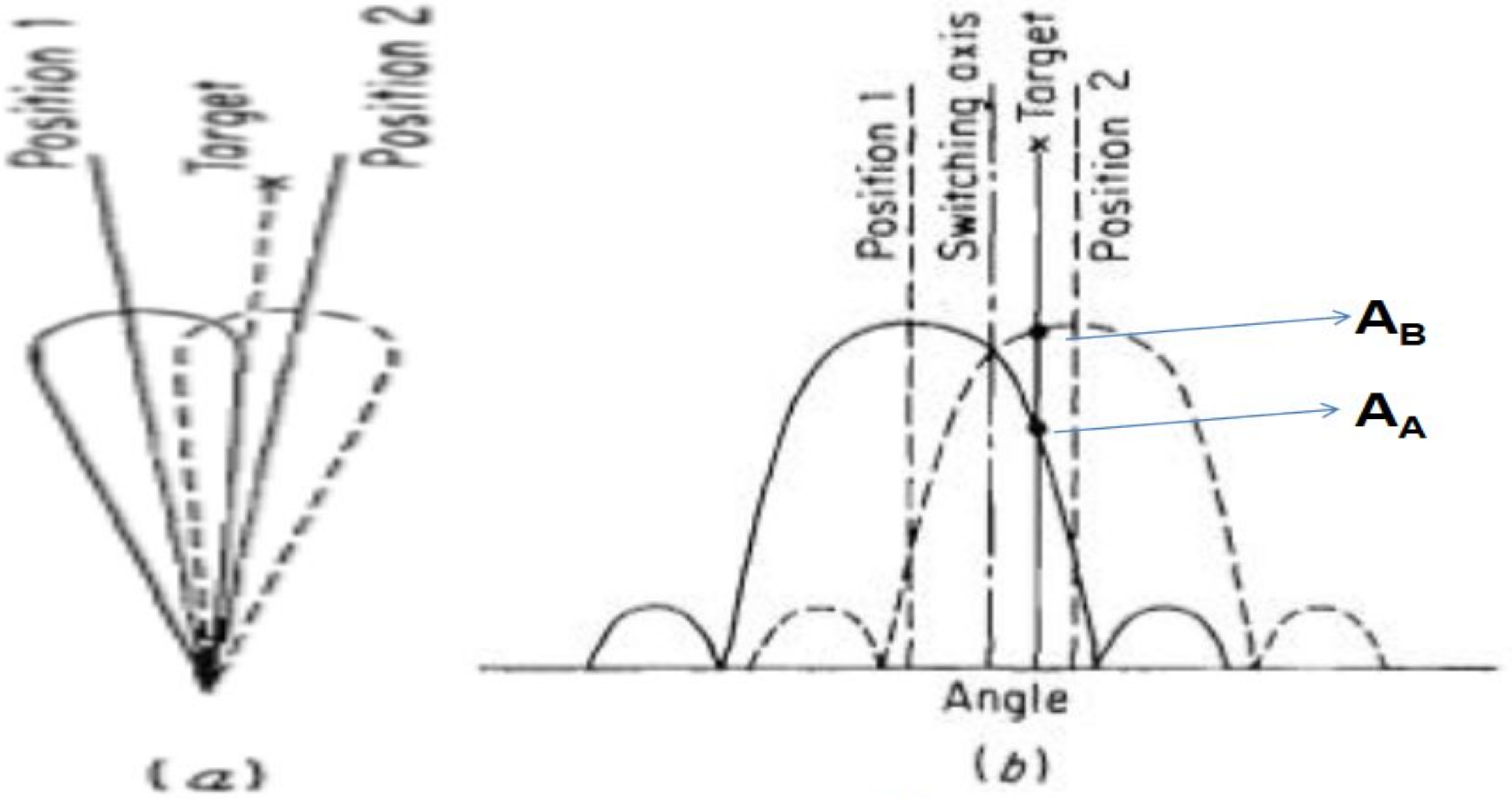


(a) Wave front phase relationships in a phase comparison monopulse radar



(b) Block diagram of a phase comparison monopulse radar (one angle coordinate).

Sequential Lobing [switching the antenna beam between two positions]

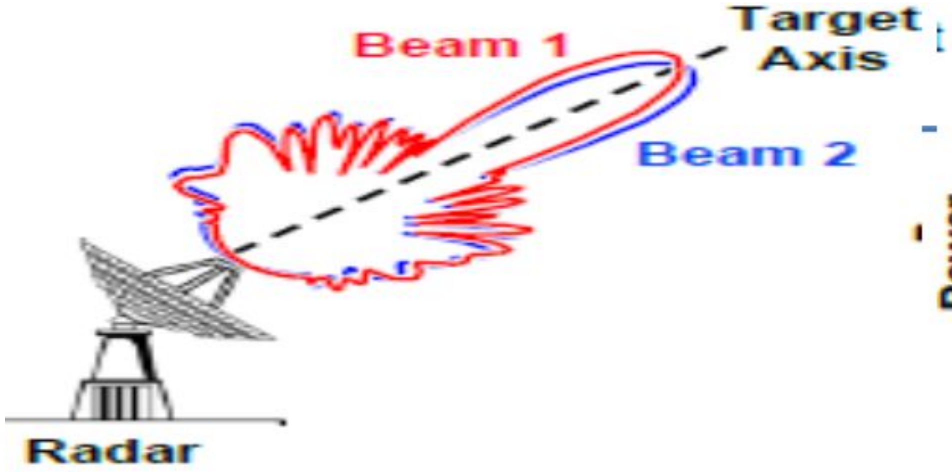


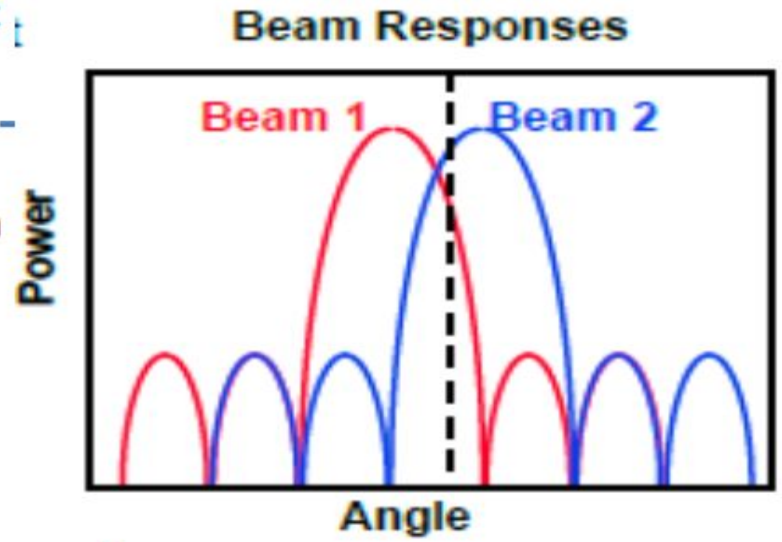
Polar representation

Rect. representation of switched antenna patterns

Lobe-switching antenna patterns and error signal (one dimension).

Sequential Lobing





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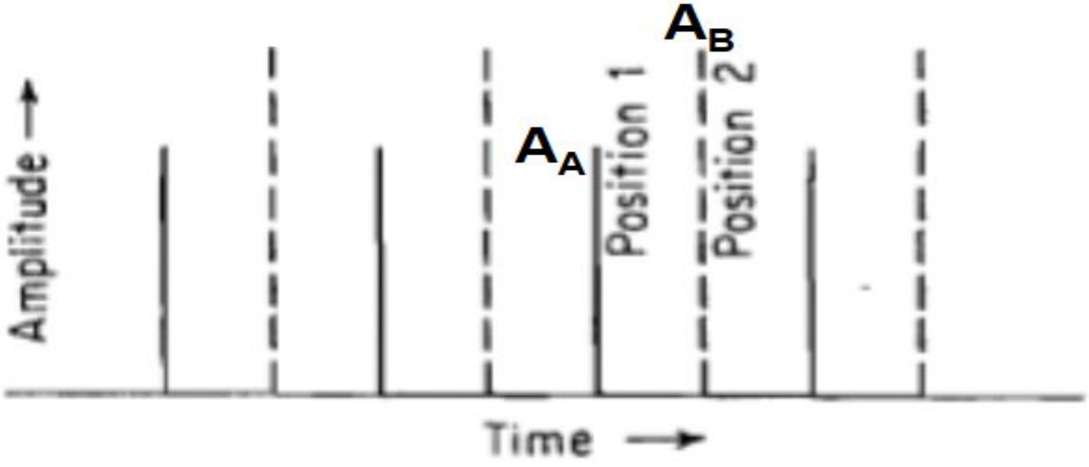
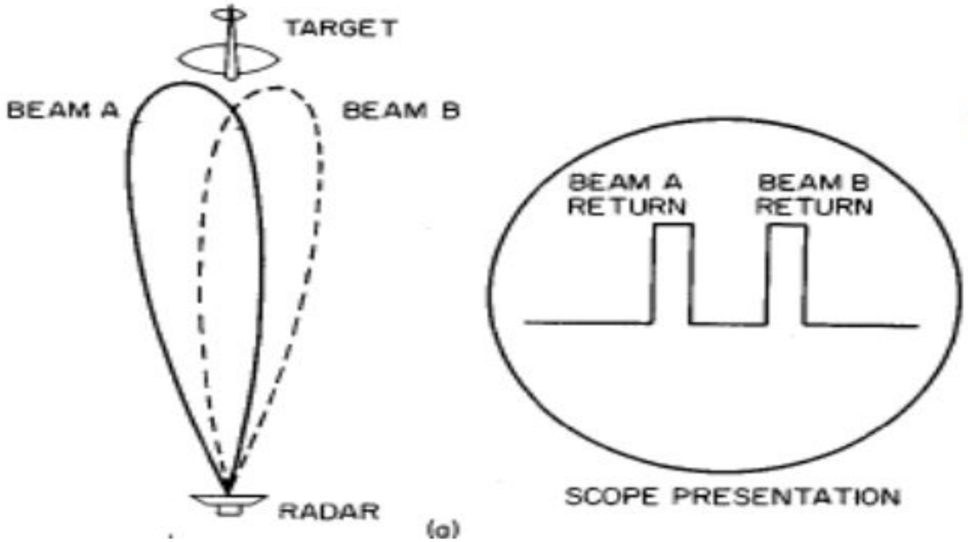
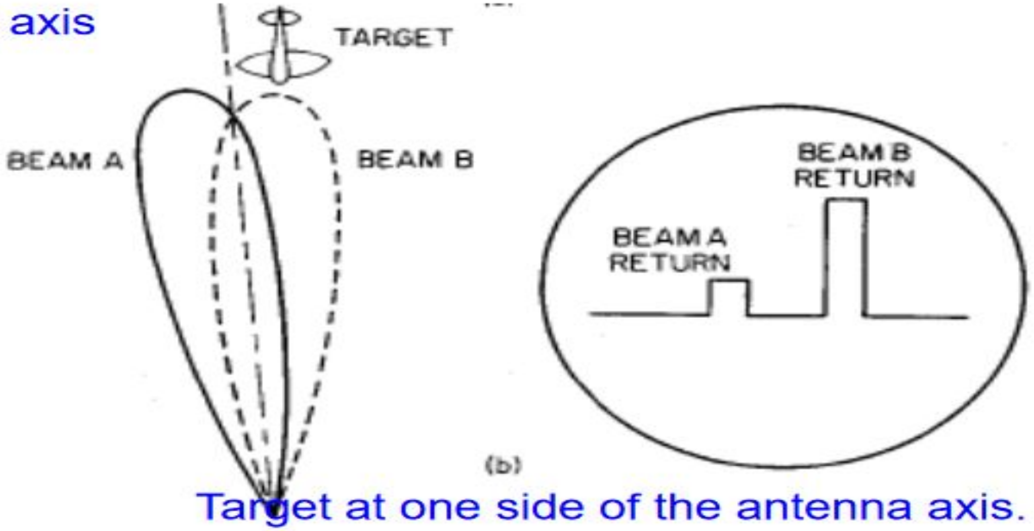


(c) error signal

Sequential Lobing



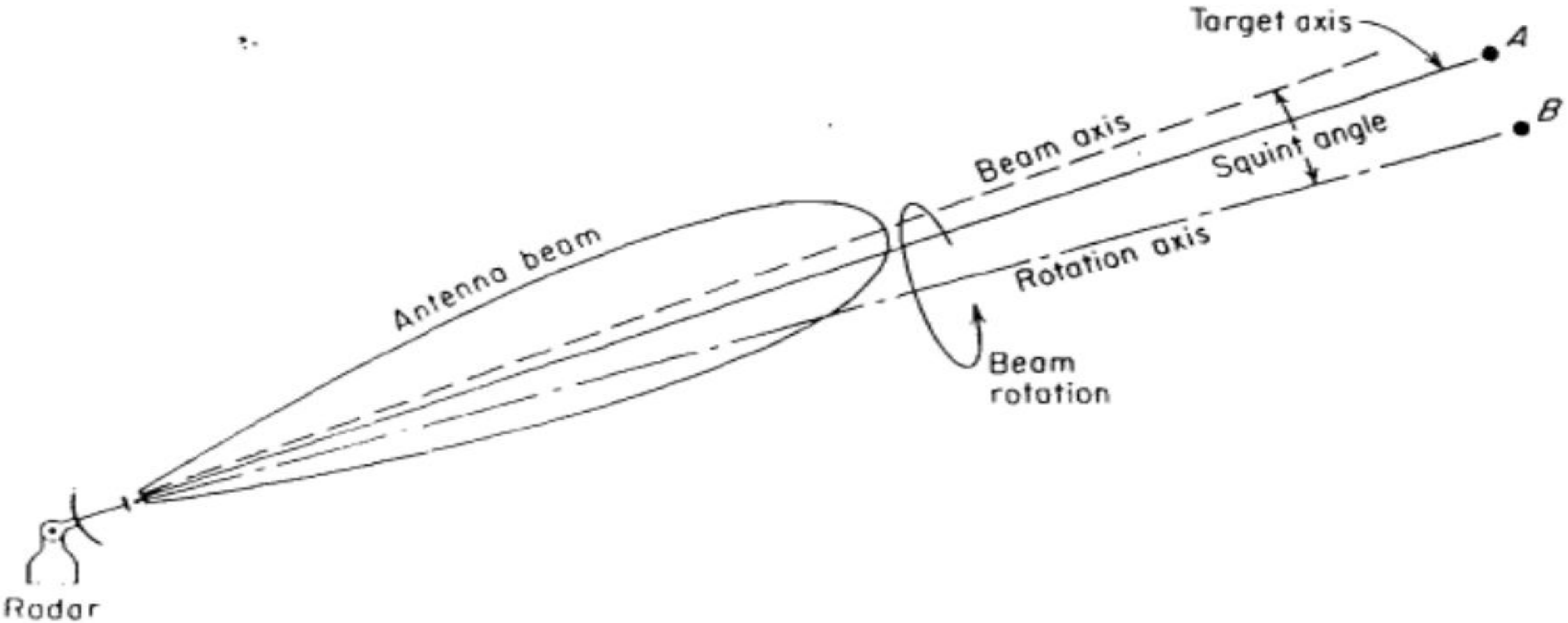
Target located on the antenna axis



Angle error sensing in one coordinate by switching the antenna beam position from one side of the target to the other,

Target at one side of the antenna axis.

Conical Scan Tracking

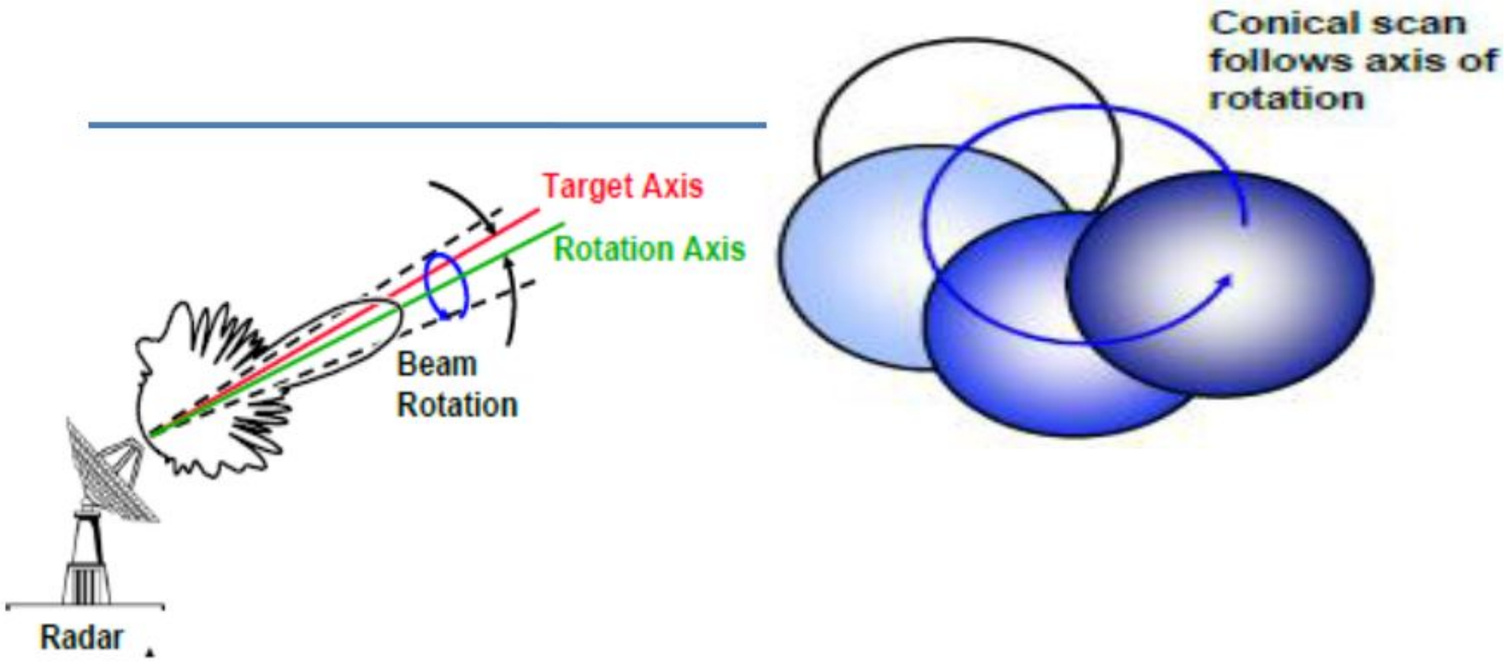


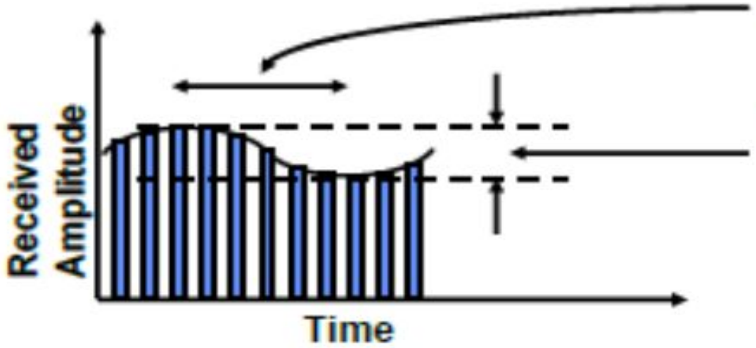
θ_T (Target angle):angle between the axis of rotation and the direction to the target.

θ_q (Squint angle):angle between the antenna-beam axis and the axis of rotation

θ_B (Beamwidth):angular separation two half power points

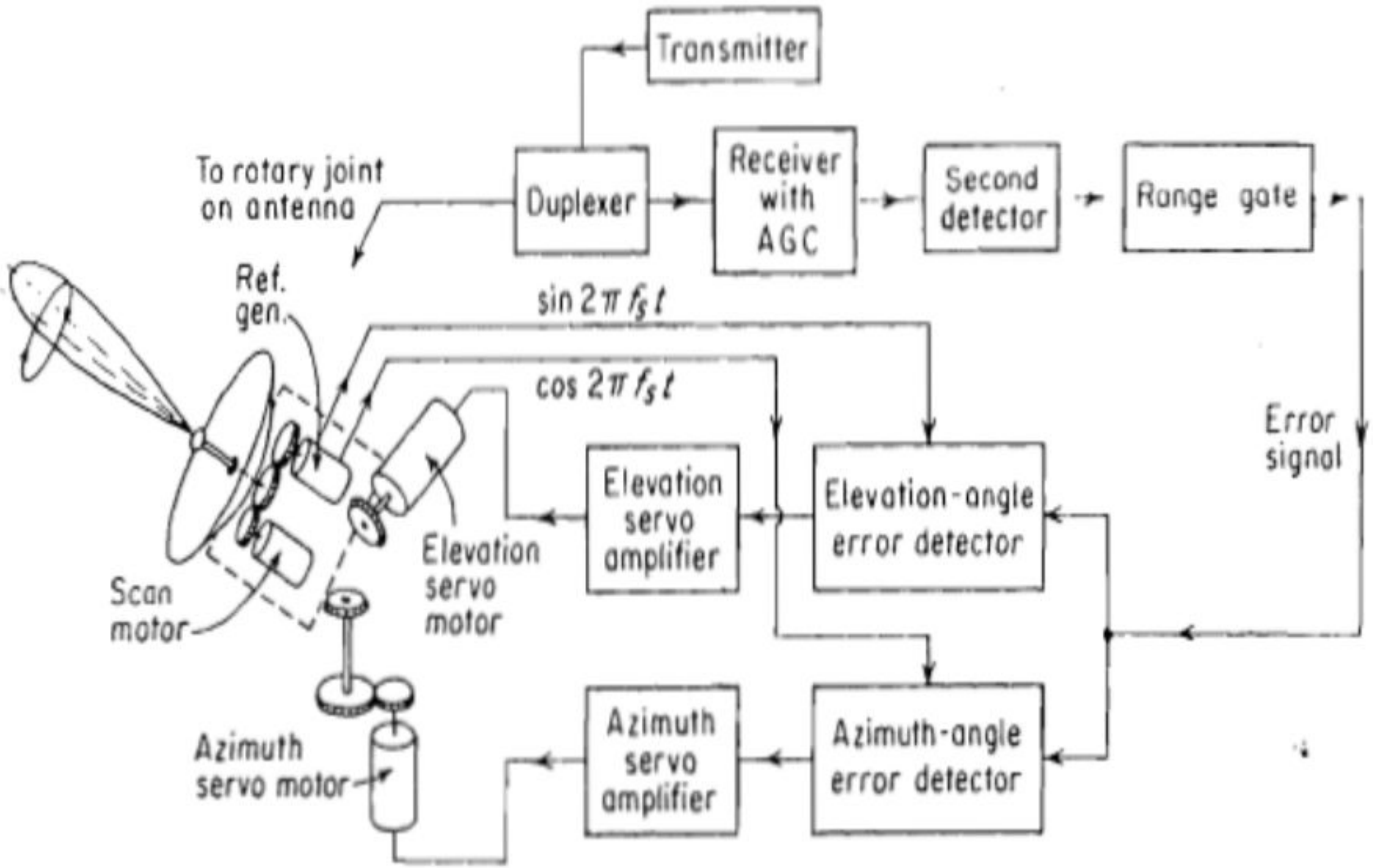
Conical Scan Tracking





- Phase of modulation gives the angle error
- Amplitude of modulation gives the beam displacement

Conical Scan Tracking



Block diagram of conical-scan tracking radar

Need of AGC

The echo-signal amplitude at the tracking-radar receiver will not be constant but will vary with time.

The three major causes of variation in amplitude are due to

(1) target cross section ($P_r \propto \sigma$)

(2) range i.e. $P_r \propto (1/R^4)$

(3) the conical scan modulation (angle-error signal), and

Limitations in conical scan radar:

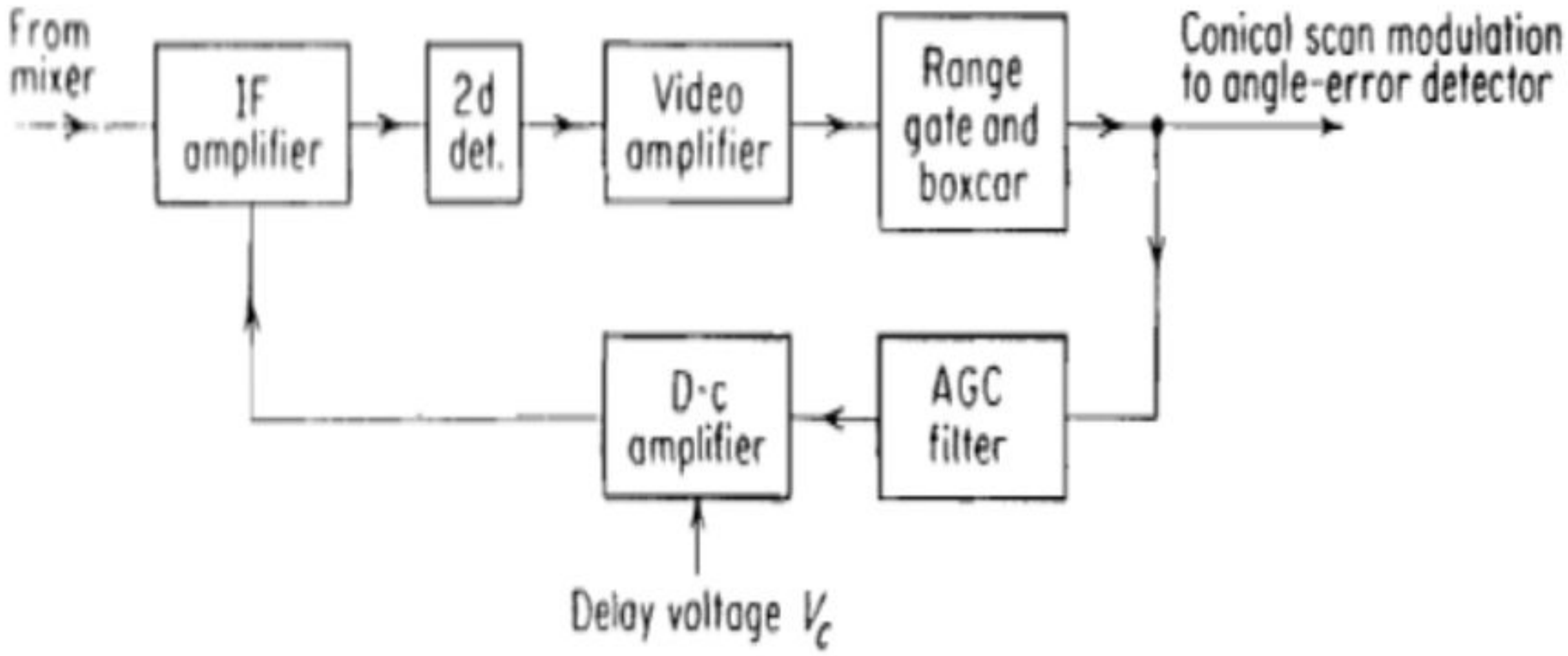
- The conical scanning radar compares the return from two directions to directly measure the location of the target.
- It creates confusion by rapid changes in signal strength.

Need of AGC

Function of AGC

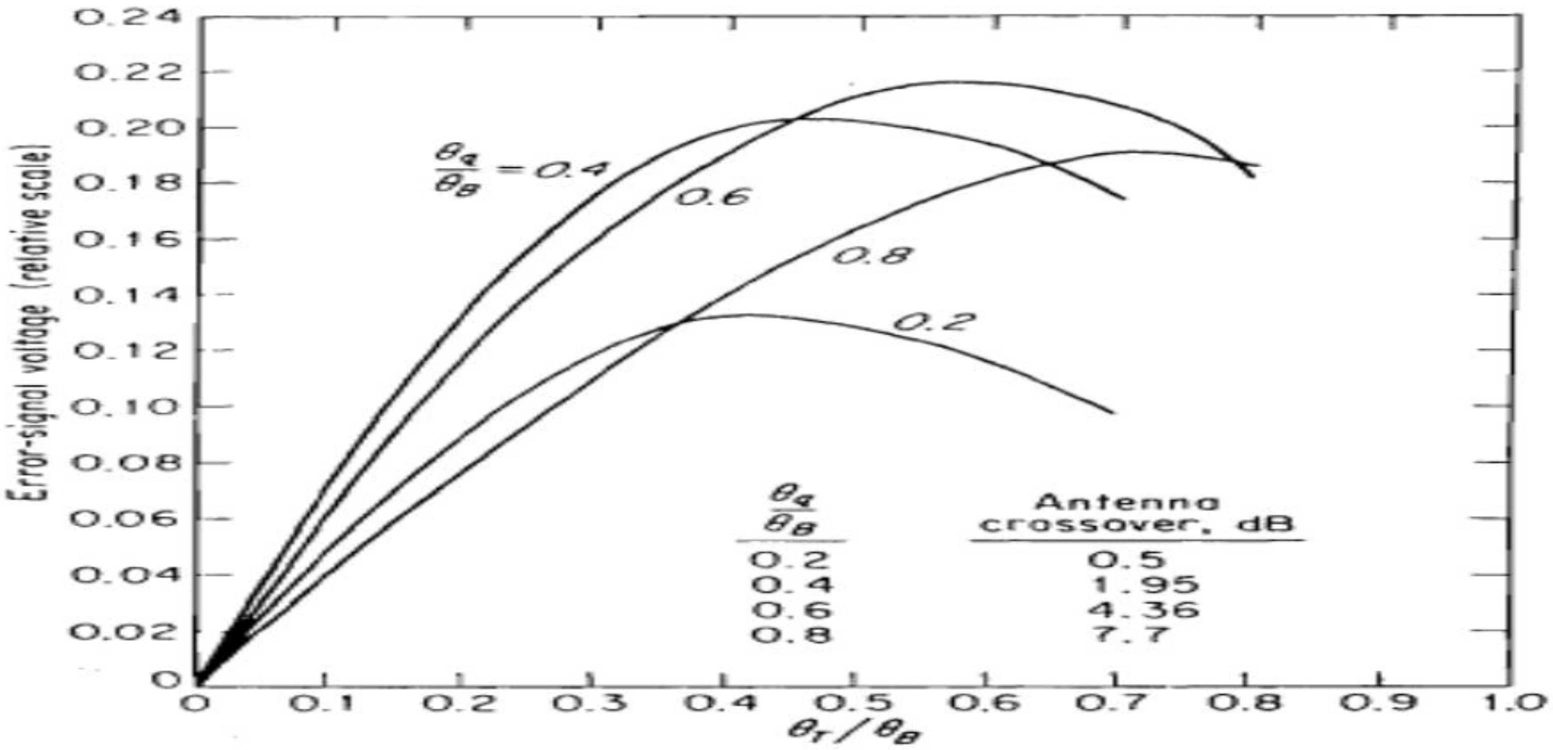
- to maintain the d-c level of the receiver output constant
- to smooth or eliminate as much of the noise like amplitude fluctuations as possible without disturbing the extraction of the desired error signal at the conical-scan frequency.
    - Results in an error signal that is a true indication of the angular pointing error
- to prevent saturation by large signals.
    - Scanning modulation and the error signal would be lost if the receiver were to saturate

AGC



Block diagram of the AGC portion of a tracking- radar receiver

Conical Scan



The angle-error signal voltage vs function (θ_T / θ_B)

θ_T (Target angle):angle between the axis of rotation and the direction to the target.

θ_q (Squint angle):angle between the antenna-beam axis and the axis of rotation

θ_B (Beamwidth):angular separation two half power points

Conical Scan

Observation:

- Greater the slope of the error signal, More accurate will be the tracking of the target.
- The maximum slope occurs for a value θ_T / θ_B slightly greater than 0.4 that corresponds to a point on the antenna pattern (the antenna crossover) about 2 dB down from the peak.
- It is the optimum crossover for maximizing the accuracy of angle tracking.
- It has been suggested that the compromise value of θ_T / θ_B be about 0.28, corresponding to a point on the antenna pattern about 1.0 dB below the peak.

Tracking Radar

Single beam on time sharing basis.

- Sequential lobing Radar and
- Conical scan Radar
  - Simpler
  - One antenna
  - Less equipment
  - Not accurate
    - RCS scintillation
    - Angle scintillation
  - No of pulses are required to extract the error signal

Multiple beam.

- Simultaneous lobing or monopulse Radar]
  - Complex
  - Multiple antennas
  - More equipments
  - Accurate
  - Single pulse is used to determine the angular error.
    - Amplitude comparison
    - Phase comparison

Limitations to Tracking Accuracy

- Major effects that determine the accuracy of a tracking radar:
  - Glint or angle noise or angular scintillation: which affects all tracking radars especially at short range.
  - Receiver noise: affects all radars and mainly determines tracking accuracy at long range.
  - RCS scintillation or Amplitude fluctuations of the target echo that bother conical scan and sequential lobing trackers but not monopulse.
  - Servo noise

Reference

- *Merrill I. Skolnik," Introduction to Radar Systems", 3rd Edition Tata Mc Graw-Hill 2008*
- https://www.iist.ac.in/sites/default/files/people/IN14204/Lecture%2028-32%20Tracking%20Radar.pdf