PPT
ON
RADAR SYSTEMS

By

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Unit I

BASICS OF RADAR

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CONTENTS :: UNIT-I

- Radar History
- Nature Of Radar
- Maximum Unambiguous Range
- Radar Wave Forms
- Radar Range Equation
- Radar Block Diagram
- Radar Frequencies
- Radar Applications
- Related Problems

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Radar History

- Radio Detection And Ranging
- Hertz
- Christian Hulsmeyer
- Albert H.Taylor and Leo C.Young
- Monostatic,Bistatic and Multistatic Radars

Nature of radar

- Radar operates by radiating energy
- Duplexer
- Echo signal
- Doppler effect

$$R = \frac{cT_R}{2}$$

- 1 Nautical mile=1.852 km

$$R(\text{km}) = 0.15 T_R(\mu s) \quad \text{or} \quad R(\text{nmi}) = 0.081 T_R(\mu s)$$

Maximum Unambiguous Range

- Echoes that arrive after the transmission of the next pulse are called second-time-around(or multiple-time-around) echoes.
- The range beyond which targets appear as second-time-around echoes is called the

Maximum ous range

$$R_{unamb} = \frac{c}{2f_p}$$

Radar Wave Forms

- Transmitted Power:: 1 Mega watt
- Pulse Width :: 1 Micro second
- Pulse Repetition Period :: 1 Milli second
- Average Power can be calculated as

  Transmitted Power * Pulse Width *Pulse Repetition Frequency
- Energy :: Transmitted Power * Pulse Width

Radar Range Equation

- If the power of the radar transmitter is denoted by Pt , and if an isotropic antenna is used (one which radiates uniformly in all directions), the power density(watts per unit area) at a distance R from the radar is equal to the transmitter power divided by the surface area 4Π R2 of an imaginary sphere of radius R,

$$\text{Power density from isotropic antenna} = \frac{P_t}{4\pi R^2}$$

- The power density at the target from an antenn a with a transmitting gain G is

$$\text{Power density from directive antenna} = \frac{P_t G}{4\pi R^2}$$

- The measure of the amount of incident power intercepted by the target and reradiated back in the direction of the radar is denoted as the radar cross section σ, and is defined by the relation

$$\text{Power density of echo signal at radar} = \frac{P_t G}{4\pi R^2} \frac{\sigma}{4\pi R^2}$$

Radar Range Equation

- If the effective area of the receiving antenna is denoted Ae, the power Pr, received bv the radar is

$$P_r = \frac{P_t G}{4\pi R^2}\frac{\sigma}{4\pi R^2}A_e = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4}$$

- The maximum radar range Rmax is the distance beyond which the target cannot be detected. It occurs when the received echo signal power P, just equals the minimum detectable signal Smin,

$$R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}}\right]^{1/4}$$

- Antenna theory gives the relationship between the tran smitting gain and
- the receiving effective area of an antenna as

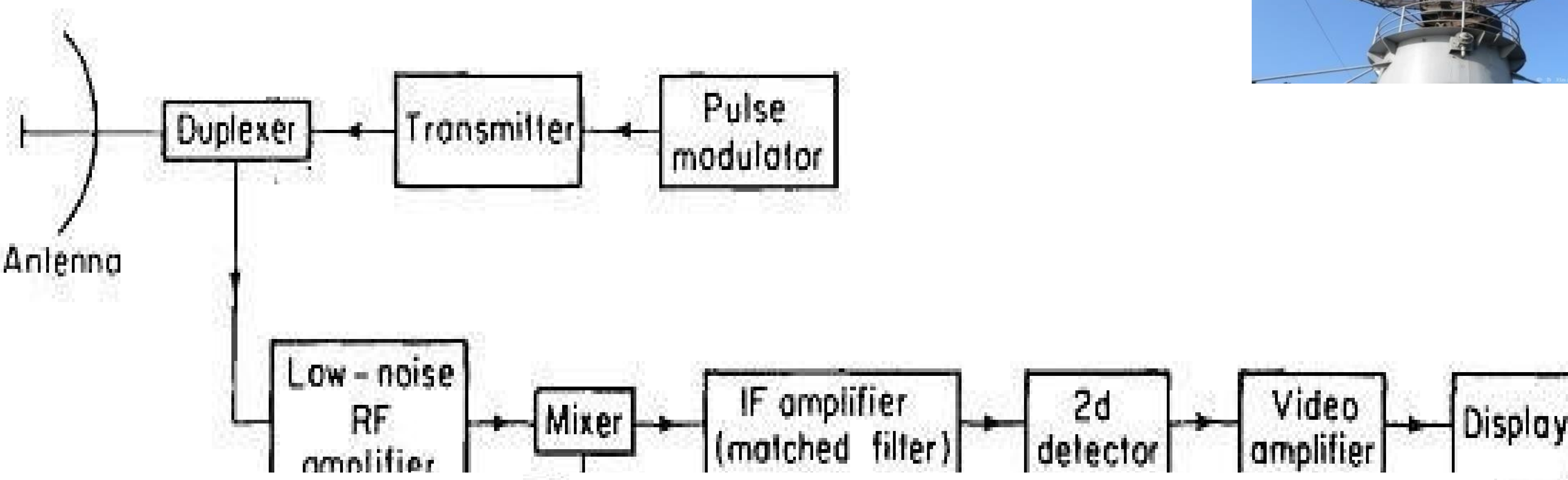
$$G = \frac{4\pi A_e}{\lambda^2}$$

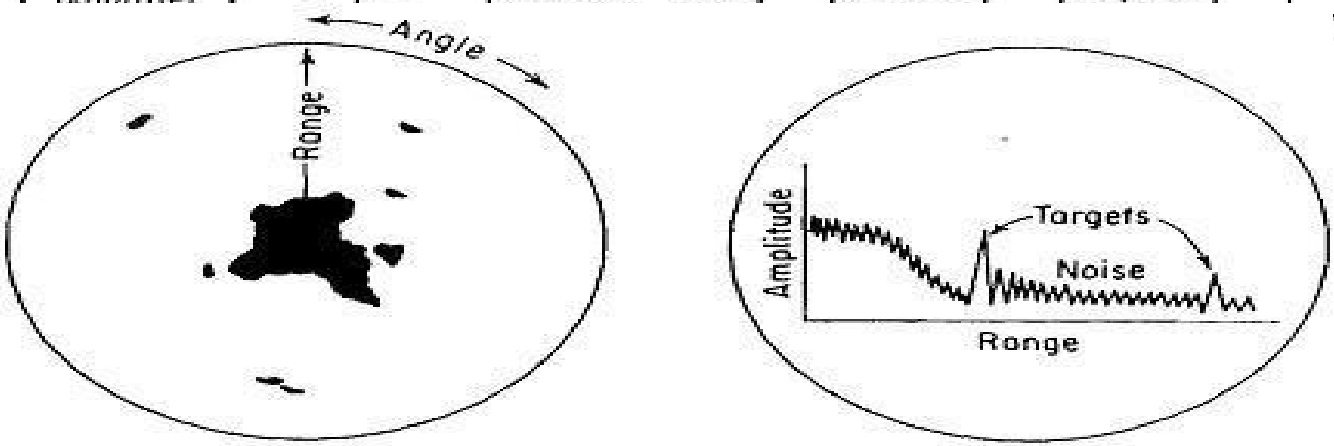
- Two other forms of the rada

$$R_{max} = \left[\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}}\right]^{1/4}$$

$$R_{max} = \left[\frac{P_t A_e^2 \sigma}{4\pi\lambda^2 S_{min}}\right]^{1/4}$$

Radar Block Diagram





(a) (b)

Radar Frequencies

Band designation	Nominal frequency range	Specific radiolocation (radar) bands based on ITU assignments for region 2
HF	3–30 MHz	
VHF	30–300 MHz	138–144 MHz
		216–225
UHF	300–1000 MHz	420–450 MHz
		890–942
L	1000–2000 MHz	1215–1400 MHz
S	2000–4000 MHz	2300–2500 MHz
		2700–3700
C	4000–8000 MHz	5250–5925 MHz
X	8000–12,000 MHz	8500–10,680 MHz
K_u	12.0–18 GHz	13.4–14.0 GHz
		15.7–17.7
K	18–27 GHz	24.05–24.25 GHz
K_a	27–40 GHz	33.4–36.0 GHz
mm	40–300 GHz	

Radar Applications

- **Air Traffic Control (ATC)**
- **Aircraft Navigation**
- **Ship Safety**
- **Remote Sensing**
- **Space**
- **Law Enforcement**
- **Military**

RADAR EQUATIONS

- Prediction of Range Performance
- Minimum Detectable Signal
- Receiver Noise and SNR
- Integration of Radar pulses
- Radar Cross Section of targets
- Transmitted Power
- Pulse Repetition Frequencies
- System Losses

Prediction of Range Performance

- The simple form of the radar equation expressed the maximum rad range Rmax, in terms of radar and target parameters

$$R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}} \right]^{1/4}$$

where P_t = transmitted power, watts
G = antenna gain
A_e = antenna effective aperture, m^2
σ = radar cross section, m^2
S_{min} = minimum detectable signal, watts

- All the parameters are to some extent under the control of the radar designer, except for the target cross section σ.

Minimum Detectable Signal

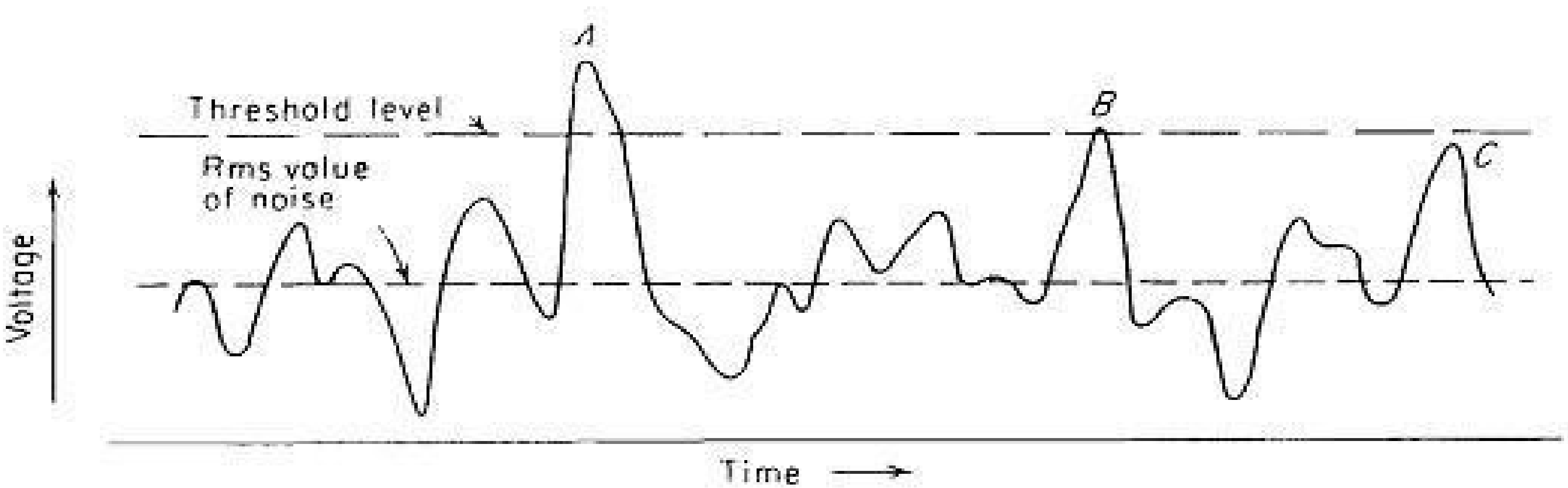
- The weakest signal the receiver can detect is called the minimum detectable signal.
- A matched filter for a radar transmitting a rectangular-shaped pulse is usually characterized by a bandwidth B approximately the reciprocal of the pulse width τ,

or $B\tau \approx 1$

- Detection is based on establishing a threshold level at the output of the receiver.
- If the receiver output exceeds the threshold, a signal is assumed to be present. This is called threshold detection.

Minimum Detectable Signal

- Probability of Miss.
- Probability of False Alarm.



Receiver Noise and SNR

$$\text{Available thermal-noise power} = kTB_n$$

- Since noise is the chief factor limiting receiver sensitivity, it is necessary to obtain some means of describing it quantitatively
- Noise is unwanted electromagnetic energy which interferes with the ability of the receiver to detect the wanted signal.
- The available thermal-noise power generated by a receiver of bandwidth Bn, (in hertz) at a temperature T (degrees Kelvin) is

Receiver Noise and SNR

- where k = Boltzmann's constant = 1.38 x 10-23 J/deg.
- Bandwidth and is given by

$$B_n = \frac{\int_{-\infty}^{\infty} |H(f)|^2 \, df}{|H(f_0)|^2}$$

$$F_n = \frac{N_o}{kT_0 B_n G_a} = \frac{\text{noise out of practical receiver}}{\text{noise out of ideal receiver at std temp } T_0}$$

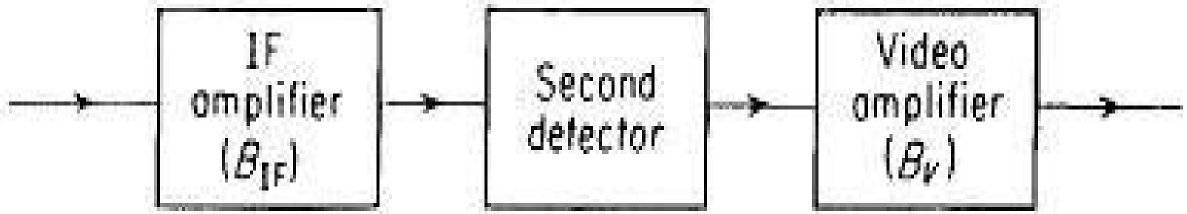
$$F_n = \frac{S_i/N_i}{S_o/N_o}$$

- If the minimum detectable signal Smin, is that value of Si corresponding to the minimum ratio of output (IF) signal-to-noise ratio (So /No)min necessary for detection.

Receiver Noise and SNR

$$S_{\min} = kT_0 B_n F_n \left(\frac{S_o}{N_o} \right)_{\min}$$

$$R_{\max}^4 = \frac{P_t G A_e \sigma}{(4\pi)^2 k T_0 B_n F_n (S_o/N_o)_{\min}}$$



- The noise entering the IF filter (the terms filter and amplifier are used interchan ability-density function g

$$p(v) = \frac{1}{\sqrt{2\pi\psi_0}} \exp \frac{-v^2}{2\psi_0}$$

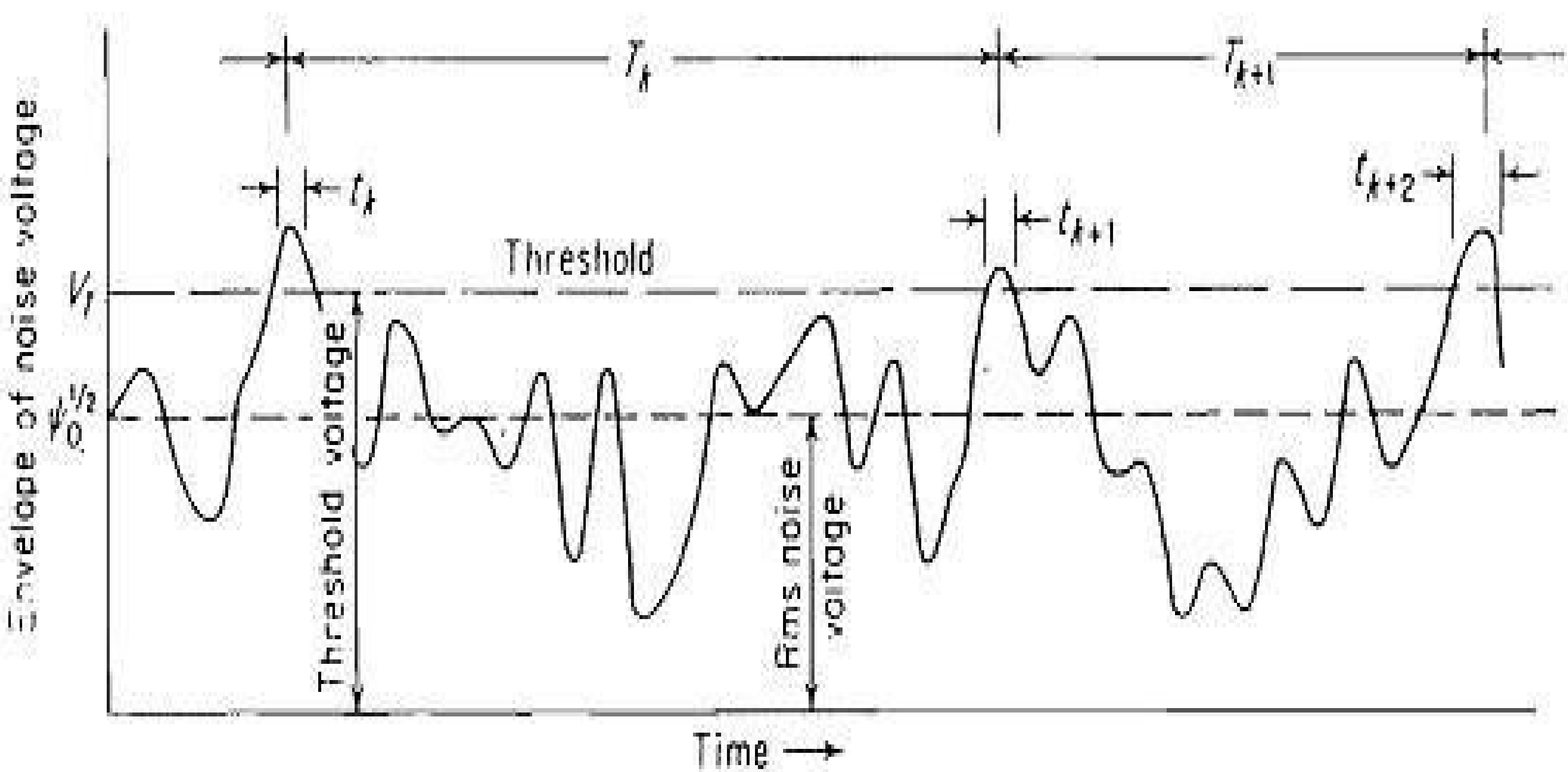
- The probability that the envelope of the noise voltage will
- lie b

$$\text{Probability } (V_1 < R < V_2) = \int_{V_1}^{V_2} \frac{R}{\psi_0} \exp\left(-\frac{R^2}{2\psi_0}\right) dR$$

- The probability that the noise voltage envelope will exceed the voltage threshold VT is

$$\text{Probability } (V_T < R < \infty) = \int_{V_T}^{\infty} \frac{R}{\psi_0} \exp\left(-\frac{R^2}{2\psi_0}\right) dR$$

$$= \exp\left(-\frac{V_T^2}{2\psi_0}\right) = P_{fa}$$



- The average time interval between crossings of the threshold by noise alone is de ... ırm time Tfa,

$$T_{fa} = \lim_{N \to \infty} \frac{1}{N} \sum_{k=1}^{N} T_k$$

$$P_{fa} = \frac{\sum_{k=1}^{N} t_k}{\sum_{k=1}^{N} T_k} = \frac{\langle t_k \rangle_{av}}{\langle T_k \rangle_{av}} = \frac{1}{T_{fa}\, B}$$

- Consider sine-wave signals of amplitude A to be present along with noise at the input to the IFfilter. The frequency of the signal is the same as the IF midband frequency fIF. The output or theenvelope detector has a probability-densi

$$p_s(R) = \frac{R}{\psi_0} \exp\left(-\frac{R^2 + A^2}{2\psi_0}\right) I_0\left(\frac{RA}{\psi_0}\right)$$

- where Io (Z) is the modified Bessel function of zero order and argument Z

Integration of Radar pulses

$$n_B = \frac{\theta_B f_p}{\dot{\theta}_s} = \frac{\theta_B f_p}{6\omega_m}$$

where θ_B = antenna beamwidth, deg
f_p = pulse repetition frequency, Hz
$\dot{\theta}_s$ = antenna scanning rate, deg/s
ω_m = antenna scan rate, rpm

$$E_i(n) = \frac{(S/N)_1}{n(S/N)_n}$$

where n = number of pulses integrated
$(S/N)_1$ = value of signal-to-noise ratio of a single pulse required to produce given probability of detection (for $n = 1$)
$(S/N)_n$ = value of signal-to-noise ratio per pulse required to produce same probability of detection when n pulses are integrated

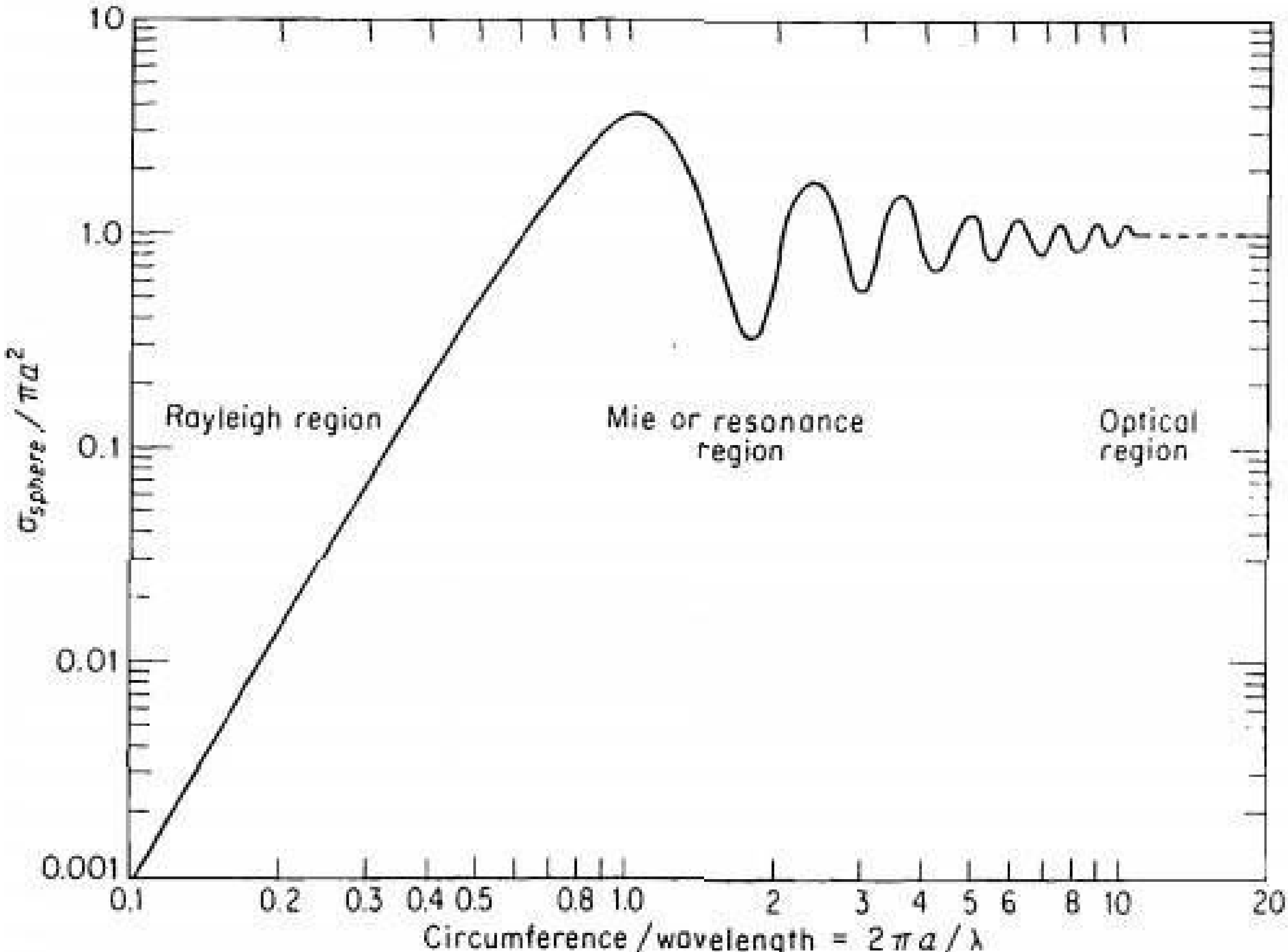
Radar Cross Section

$$\sigma = \frac{\text{power reflected toward source/unit solid angle}}{\text{incident power density}/4\pi} = \lim_{R\to\infty} 4\pi R^2 \left|\frac{E_r}{E_i}\right|^2$$

where R = distance between radar and target

E_r = reflected field strength at radar

E_i = strength of incident field at target



10
1.0
0.1
0.01
0.001
$\sigma_{sphere} / \pi a^2$
Rayleigh region
Mie or resonance region
Optical region
0.1
0.2
0.3
0.4
0.5
0.8
1.0
2
3
4
5
6
8
10
20
Circumference / wavelength = $2\pi a / \lambda$

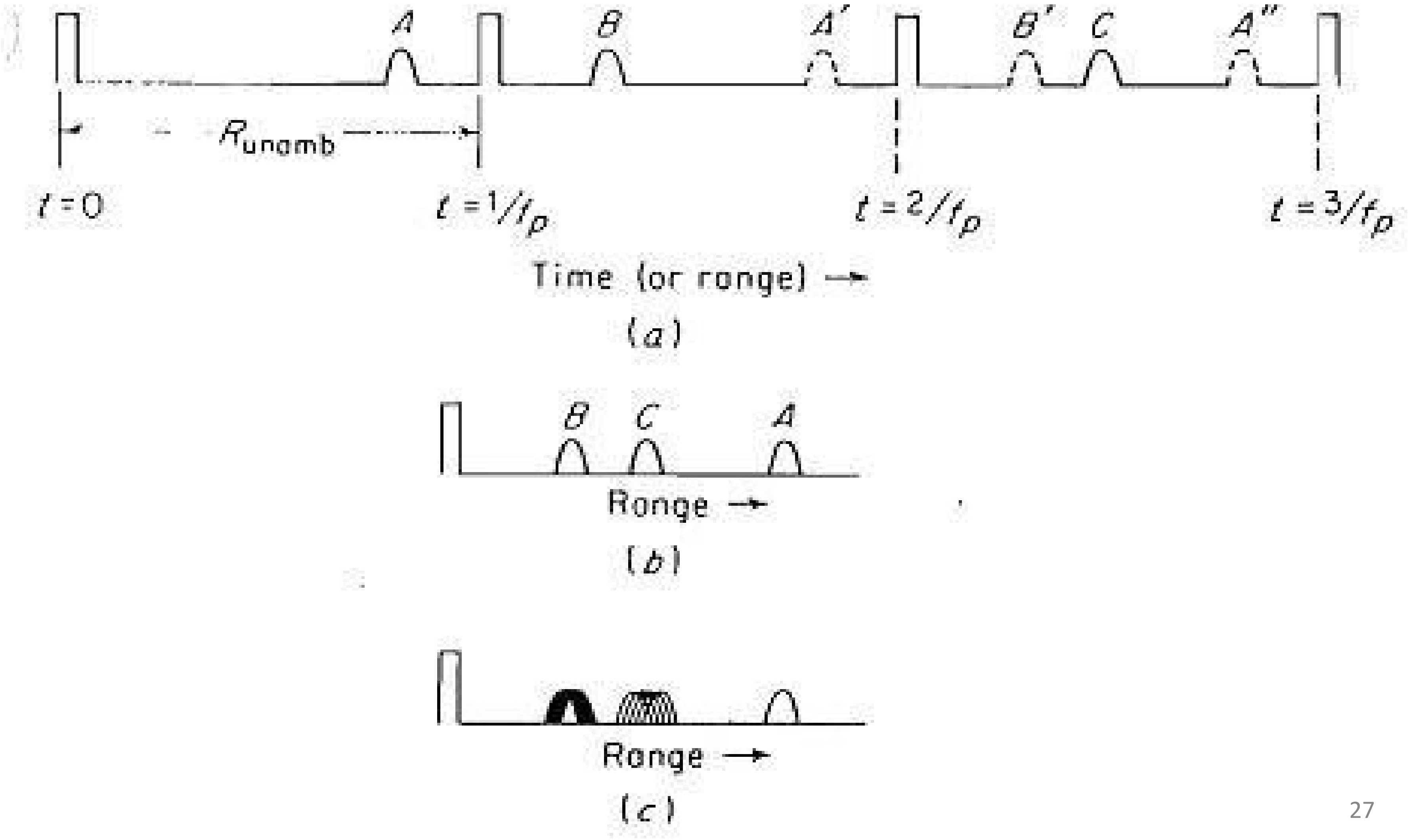
Transmitted Power

$$P_{av} = \frac{P_t \tau}{T_p} = P_t \tau f_p$$

$$R_{max}^4 = \frac{P_{av} G A_e \sigma n E_i(n)}{(4\pi)^2 k T_0 F_n (B_n \tau)(S/N)_1 f_p}$$

$$R_{max}^4 = \frac{E_t G A_e \sigma n E_i(n)}{(4\pi)^2 k T_0 F_n (B_n \tau)(S/N)_1}$$

Pulse Repetition Frequency



- Collapsing loss

$$L_i(m, n) = \frac{L_i(m+n)}{L_i(n)}$$

- Operator loss

- Field Degradation

- Propogation Effects

CONTENTS :: UNIT-II

- Doppler Effect
- CW Radar Block Diagram
- Isolation Between Transmitter and Receiver
- Non Zero IF Receiver
- Receiver Bandwidth Requirements
- Identification of Doppler Direction in CW Radar
- Applications of CW Radar
- CW Radar Tracking Illuminator

Doppler Effect

Separate antennas for transmission and
reception help segregate the weak echo from the strong leakage signal

Doppler angular frequency ωd given by

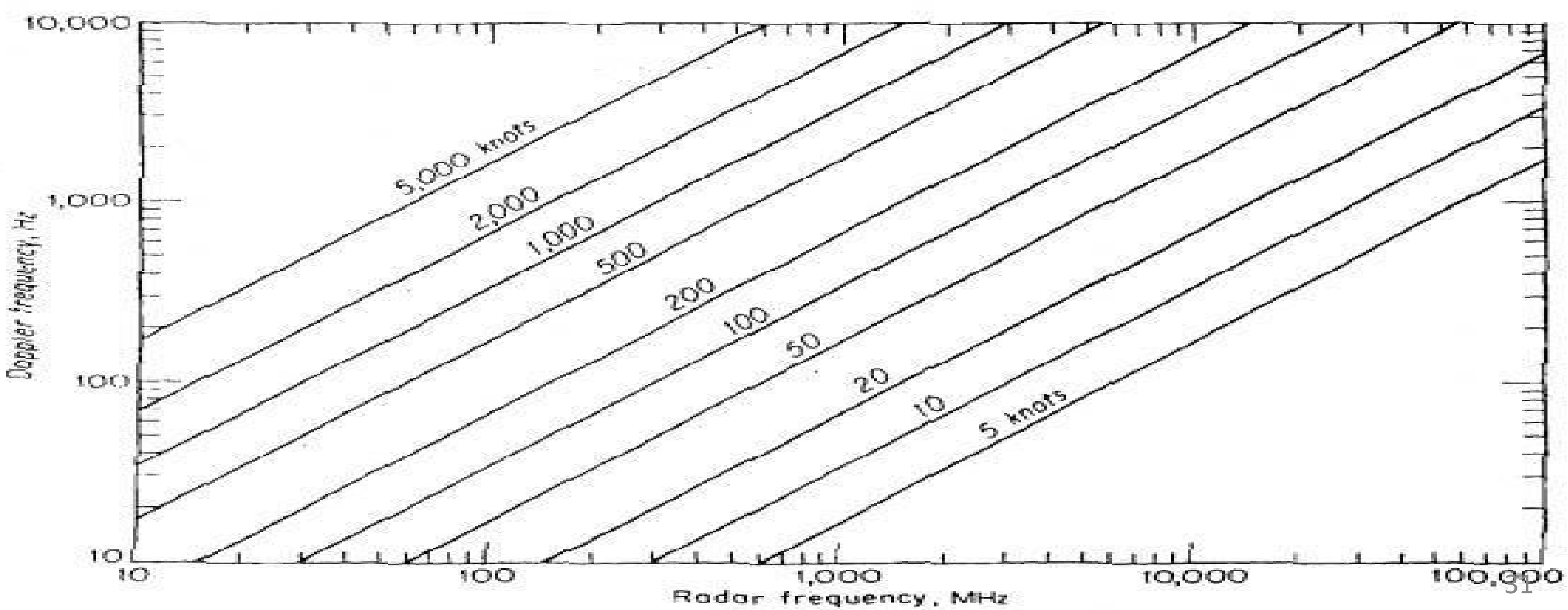
$$\frac{4\pi}{\lambda}\frac{dR}{dt} = \frac{4\pi v_r}{\lambda}$$

Where,
fd = Doppler frequency shift
vr = relative (or radial) velocity of target with to radar.
The Doppler frequency shift is *fd = 2* vr / λ = 2* vr **
fo / c where,
fo = transmitted frequency
c = velocity of propagation = 3 x 108m/s. If *fd is in*
*hertz vr in knots, and λ in meters, fd = 1.03 * vr / λ*

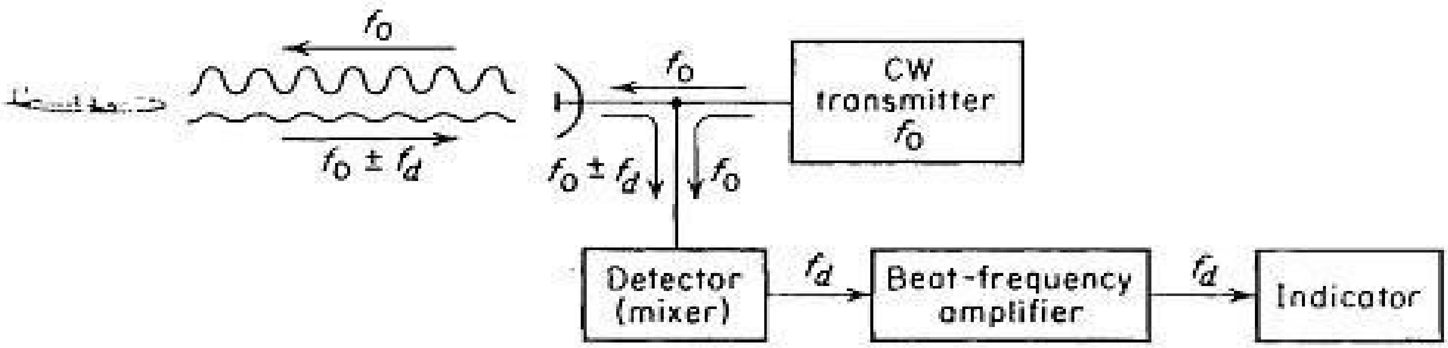
Doppler Effect

•The relative velocity may be written *vr = v cos ϑ, where v is the target speed and ϑ is the*

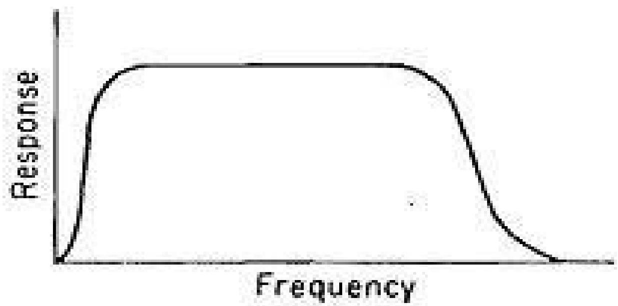
- Angle made by the target trajectory and the line joining radar and target. When θ = 0. The Doppler frequency is maximum.
- The Doppler is zero when the trajectory is perpendicular to theradar line of sight (θ = 90°)



CW Radar Block Diagram



(a)



(b)

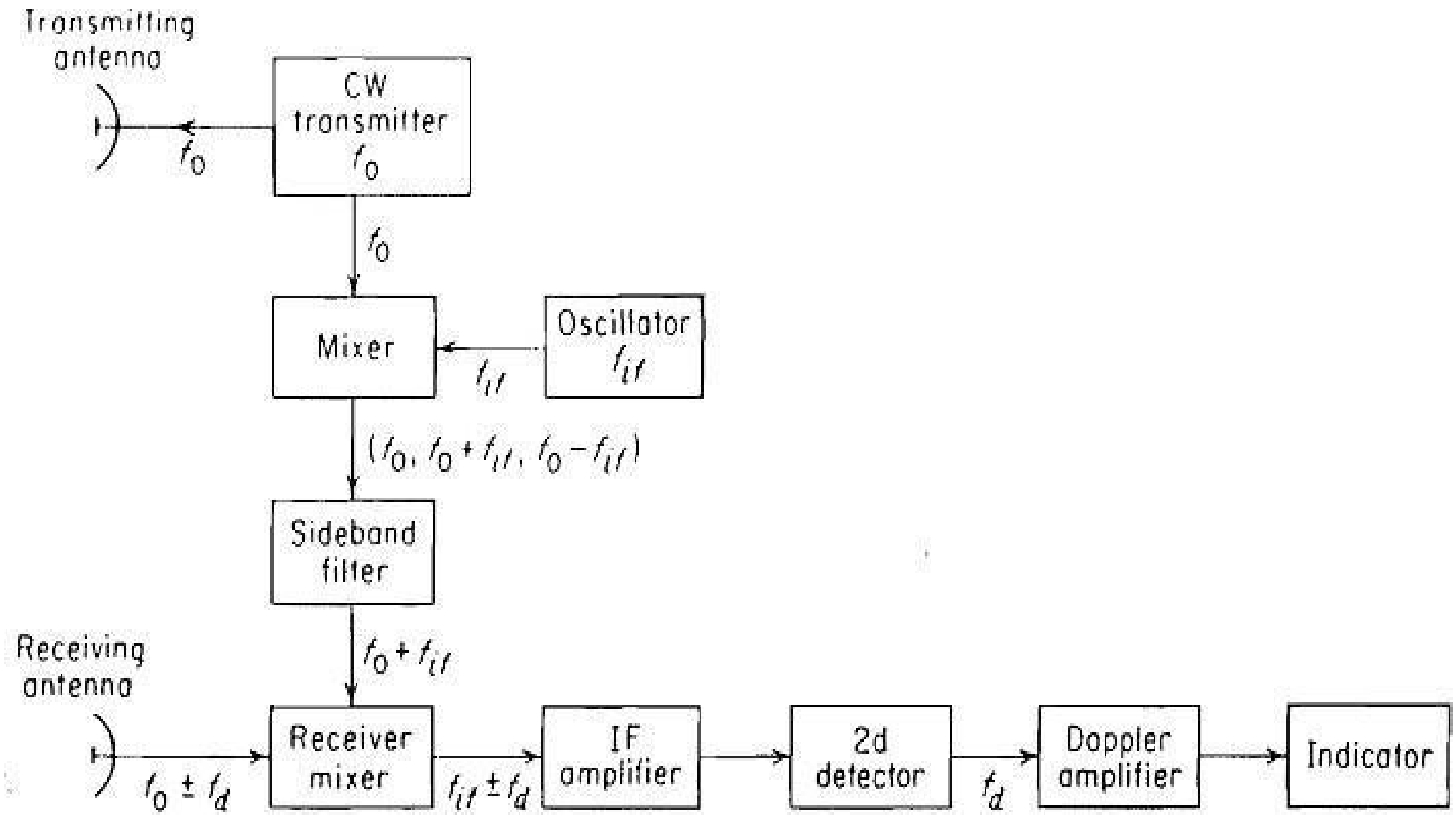
Isolation Between Transmitter and Receiver

- Isolation betweenthe transmitted and the received signals is achieved via separation in frequency as a result of the doppler effect.
- There are two practical effects which limit the amount of transmitter leakage power which can be tolerated at the receiver.
- (1) The maximum amount of power the receiver input circuitry can withstand before it is physically damaged or its sensitivity reduced
- (2) The amount of transmitter noise due to hum, microphonics etc.

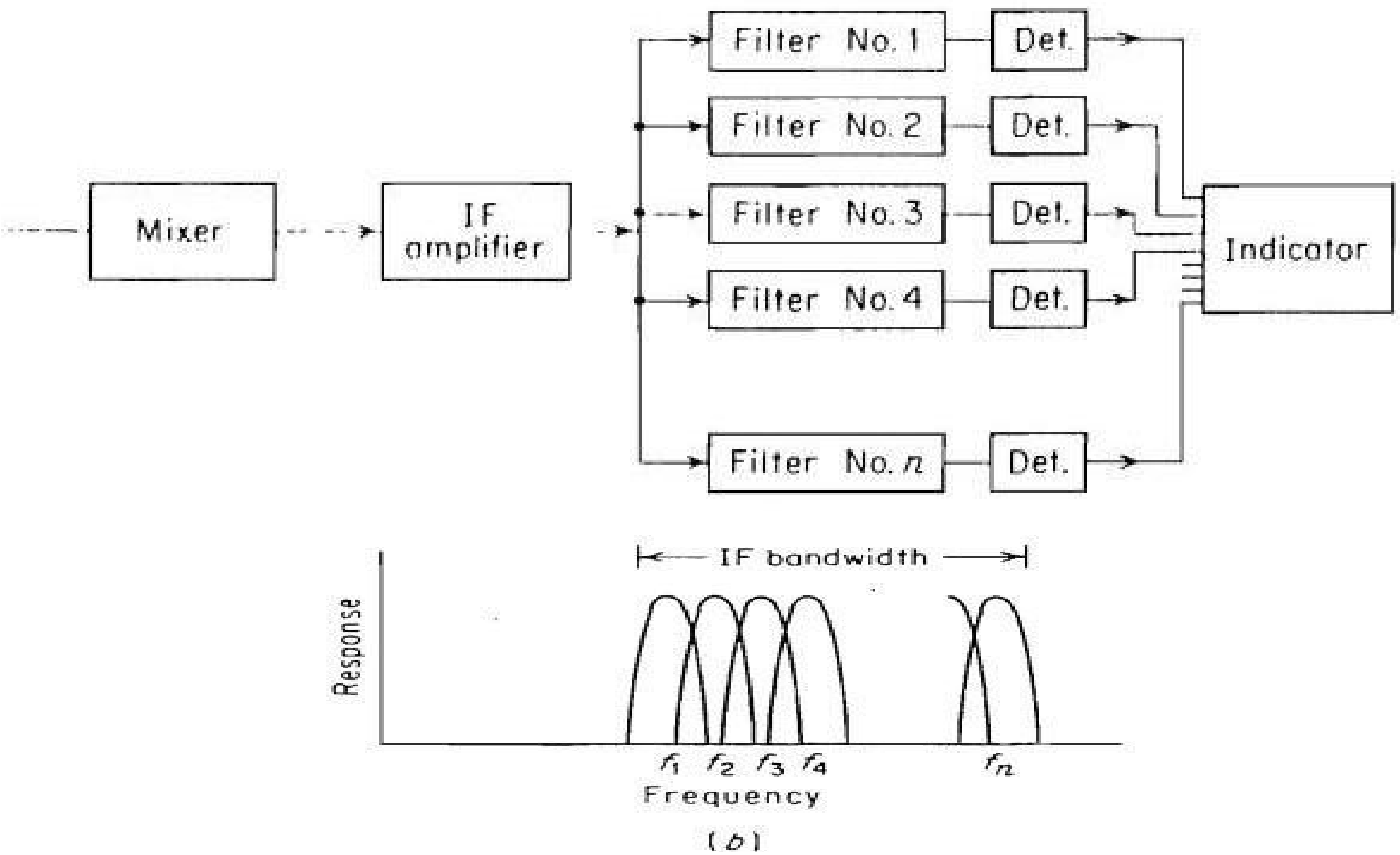
Isolation Between Transmitter and Receiver

- The amount of isolation which can be readily achieved between the arms of practical hybrid junctions such as the magic-T is of the order of 20 to 30 dB.
- Separate polarizations
- VSWR
- Separate antennas
- Dynamic cancellation of leakage

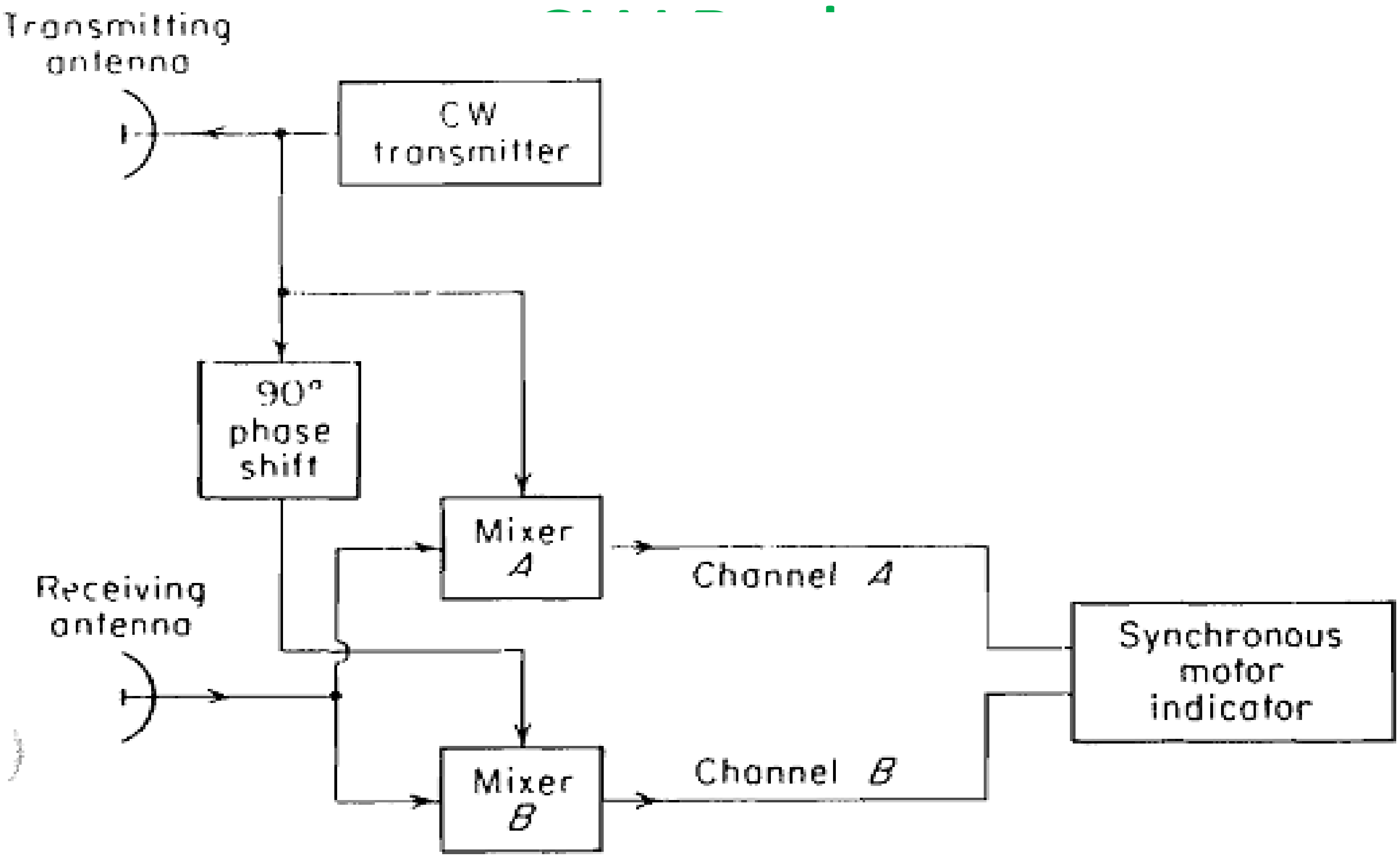
Non Zero IF Receiver



Receiver Bandwidth Requirements



Identification of Doppler Direction in



Identification of Doppler Direction in CW Radar

- The outputs from the two channels are

$EA(+) = K2\ E0 \cos(wd\ t + \varphi)$

$EB(+) = K2\ E0 \cos(wd\ t + \varphi + \pi/2)$

- If the targets are receding (negative doppler), the outputs from the two channels are

$EA(-) = K2\ E0 \cos(wd\ t - \varphi)$

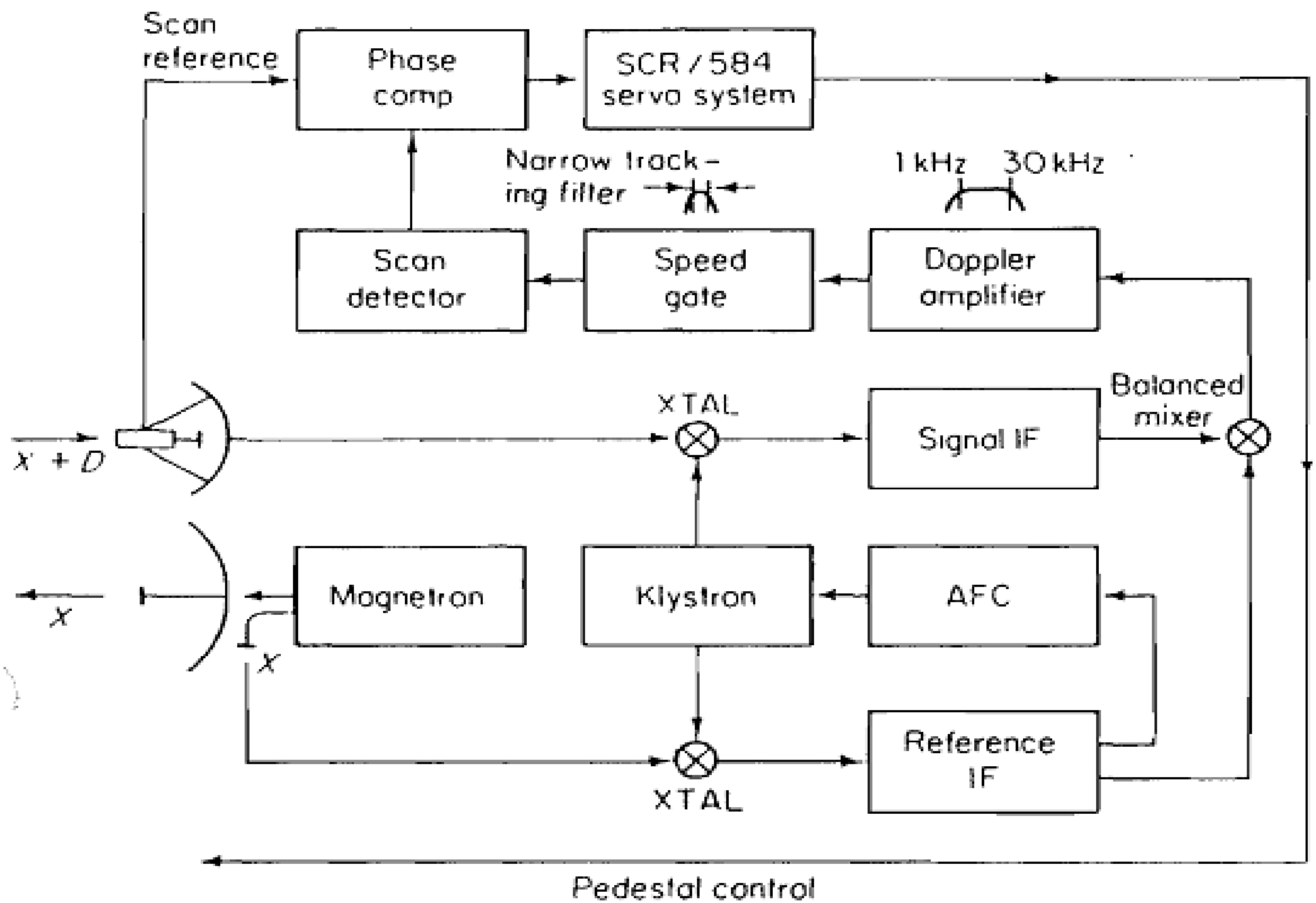
$EB(-) = K2\ E0 \cos(wd\ t - \varphi - \pi/2)$

- The direction of motor rotation is an indication of the direction of the target motion.

Applications of CW Radar

- Police speed monitor
- Collision avoidance.
- Control of traffic lights
- CW radar can be used as a speedometer to replace the conventional tachometer in Railways
- Warning of approaching trains.
- Speed of large ships.
- Velocity of missiles

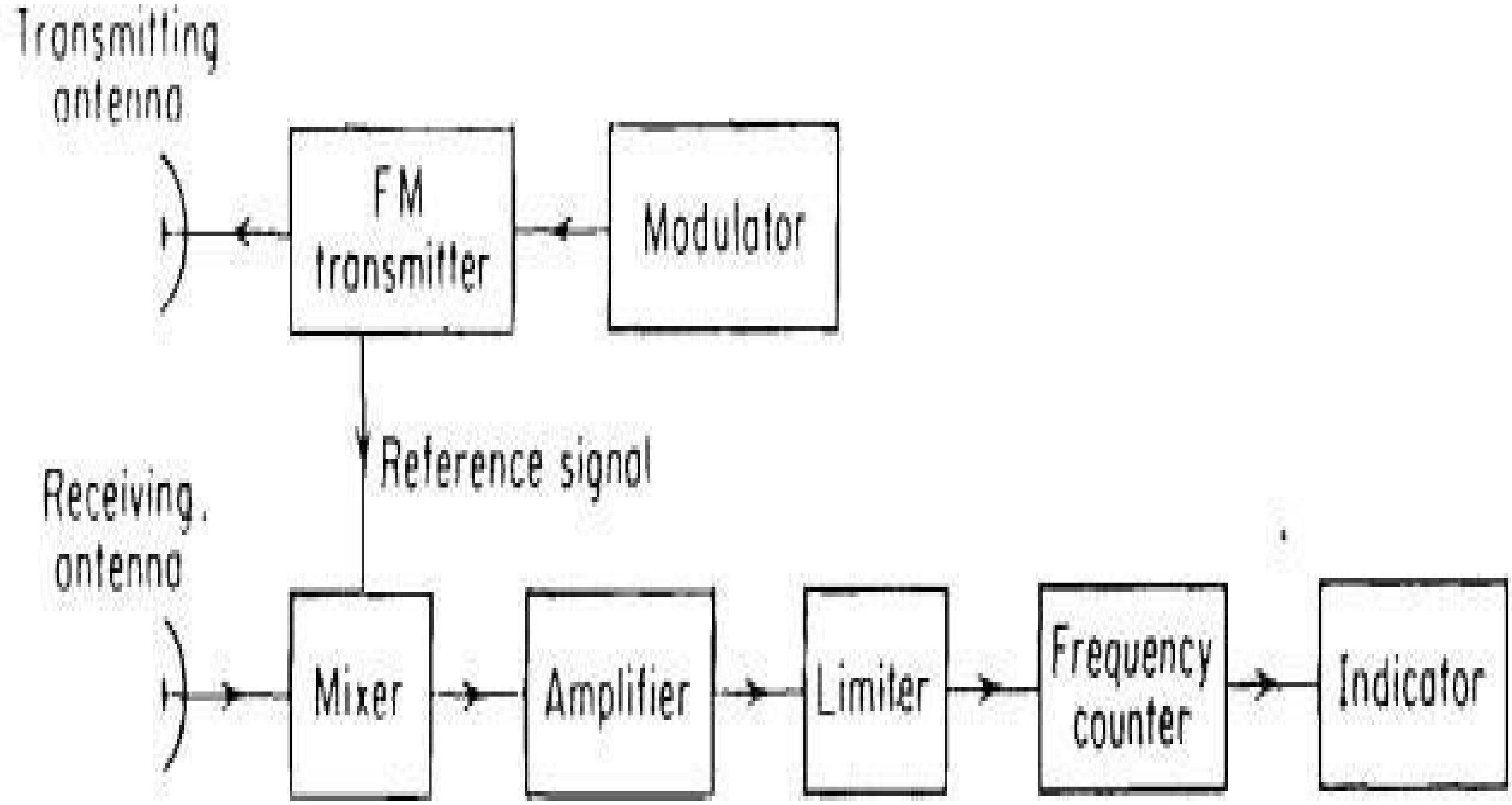
CW Radar Tracking Illuminator



FM-CW RADAR

- FMCW Radar
- Range and Doppler Measurement
- Approaching and Receding Targets
- FMCW Altimeter
- Measurement Errors
- Unwanted Signals
- Sinusoidal Modulation
- Multiple Frequency CW Radar

FMCW Radar


Transmitting antenna
FM transmitter
Modulator
Reference signal
Receiving antenna
Mixer
Amplifier
Limiter
Frequency counter
Indicator

Range and Doppler Measurement

- If the rate of change of the carrier frequency is $f0$*, the beat frequency is*

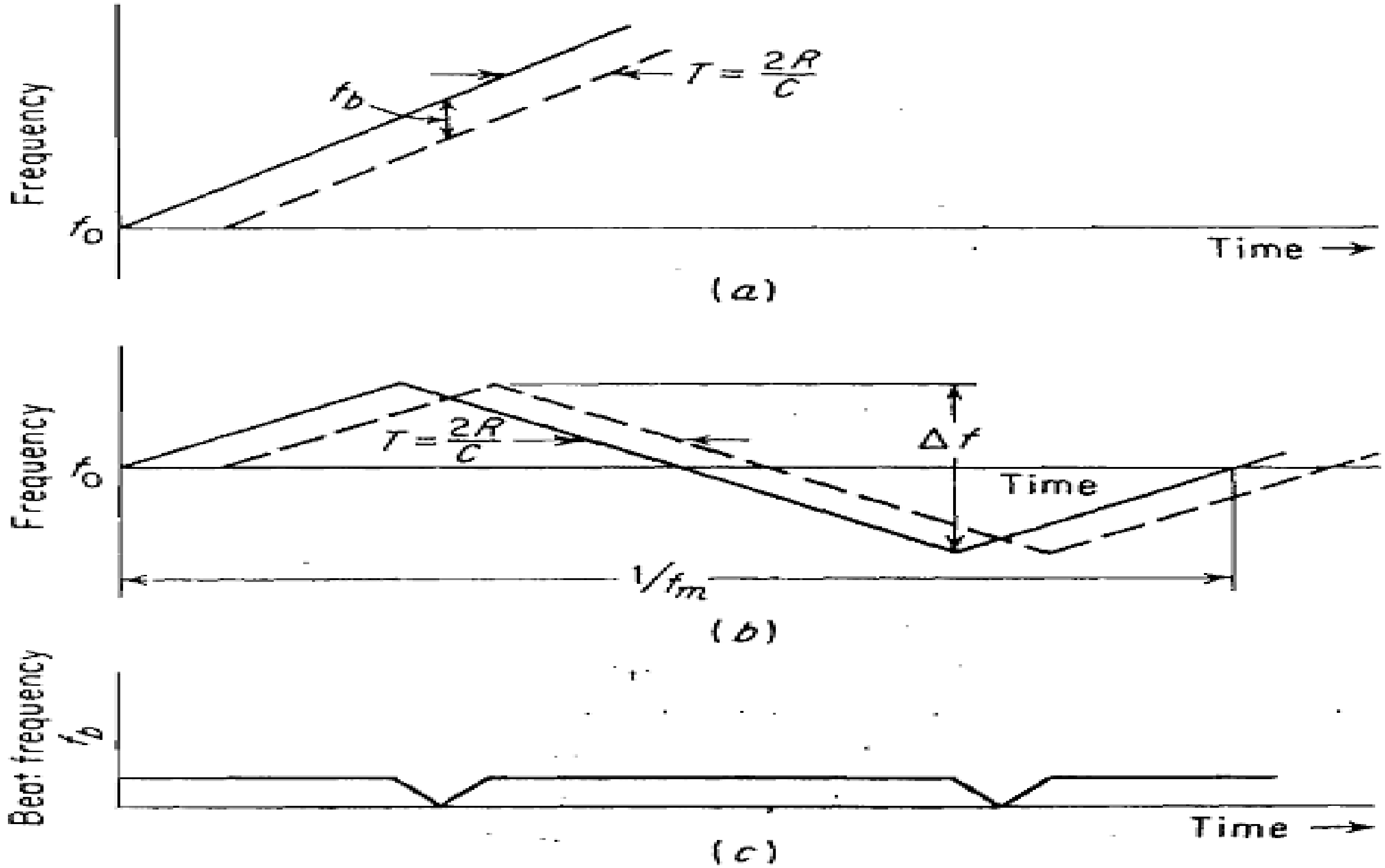
$fr = f0\,T = 2\,R\,f0 / c$

- If the frequency is modulated at a rate fm *over a range* Δf*, the beat* frequency is

$$fr = 2 * 2\,R\,fm / c = 4\,R\,fm\,\Delta f / c$$

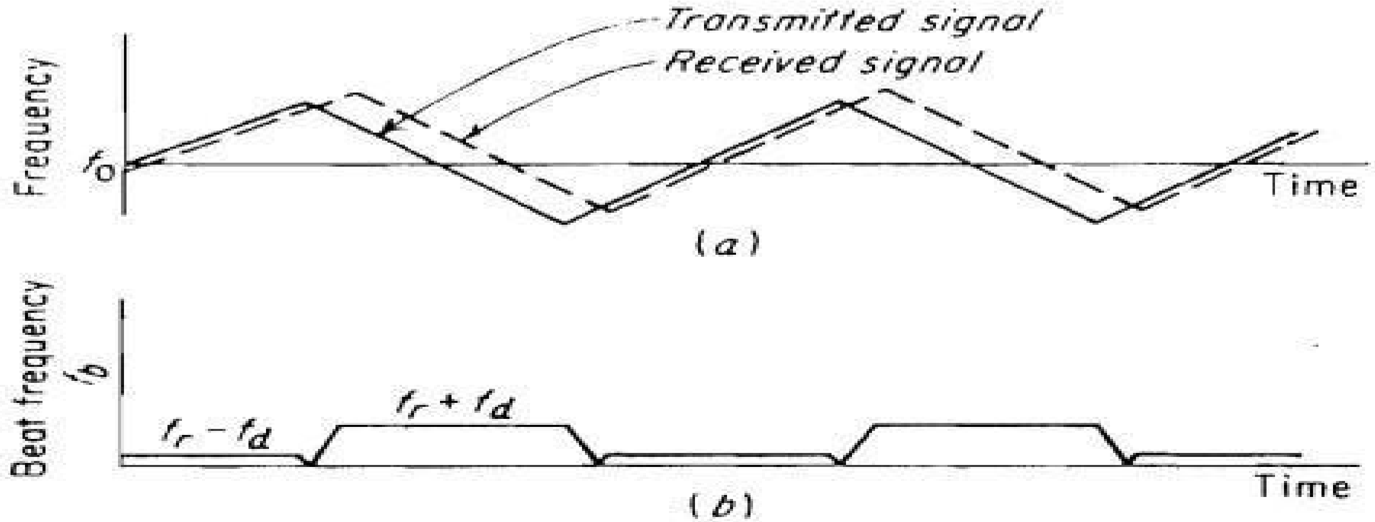
- Measurement of the beat frequency determines the range R.

$$R = c\,fr / 4\,fm\,\Delta f$$



(a) Linear frequency modulation (b) triangular frequency modulation; (c) beat note of (b).

Range and Doppler Measurement



(a) Transmitted (solid curve) and echo (dashedcurve)

(b) beat frequency

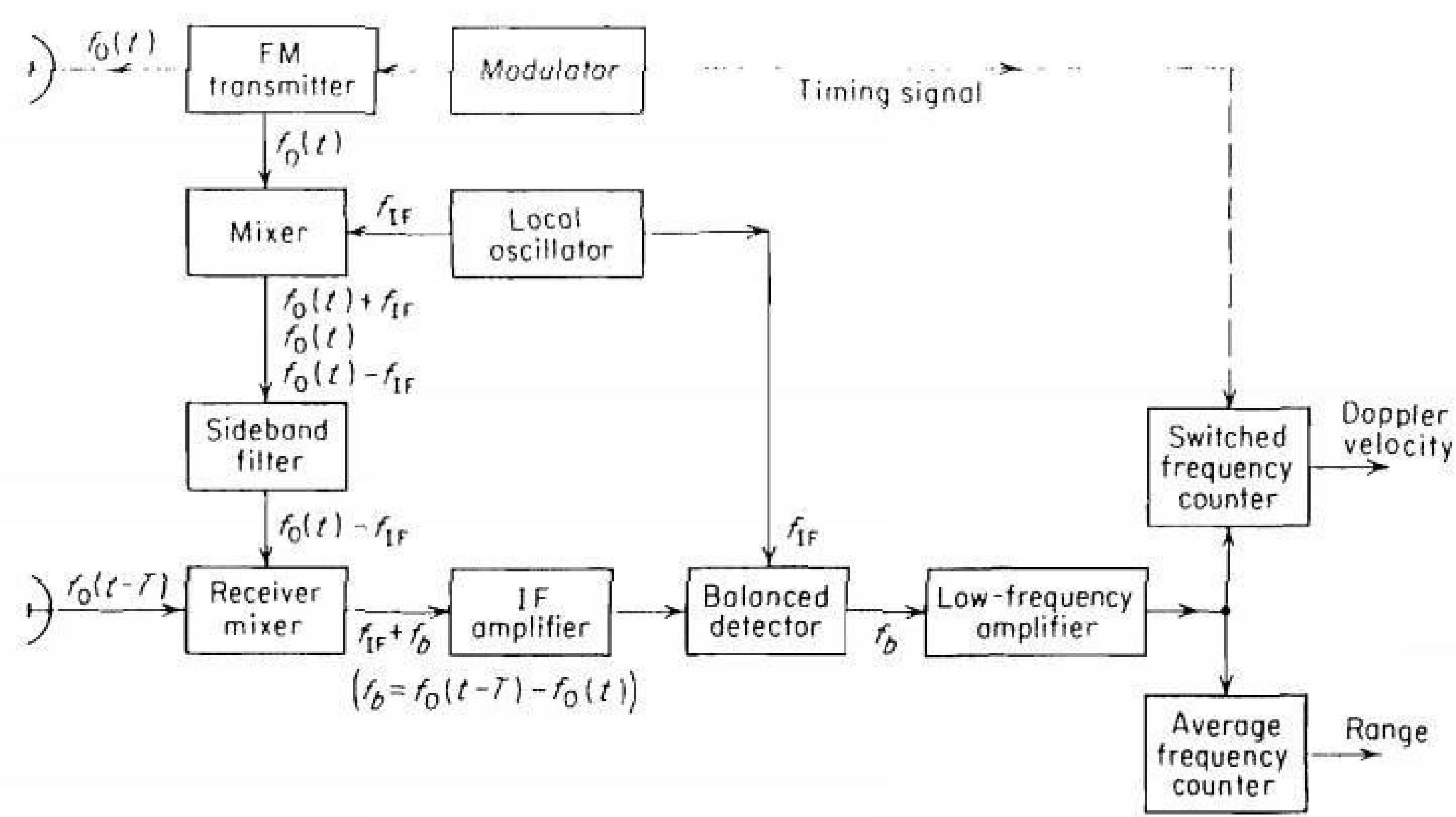
Approaching and Receding Targets

- FM cycle will be the difference between the beat frequency due to the range fr, and the doppler frequency shift fd
- fb(up) = fr - fd
- fb(down) = fr + fd

•The range frequency fr, may be extracted by measuring the average beat frequency that is,

- fr = 1/2[fb(up) + fb(down)].
- fd = 1/2[fb(up)-fb(down)].
- fr > fd   Target Approaching
- fr < fd   Target Receding

FMCW Altimeter



Measurement Errors

- The average number of cycles N of the beat frequency fb in one period of the modulation cycle *fm is fb /fm , where the bar over ,* denotes time average.
- Which measures the number of cycles or half cycles of the beat during the modulation period.
- The total cycle count is a discrete- number since the counter is unable to measure fractions of a cycle.
- The discreteness of the frequency measurement gives rise to an error called the fixed error, or step erroror quantization error

Measurement Errors

- $R = c\,N / 4\,\Delta f$
- Where, R = range (altitude). m

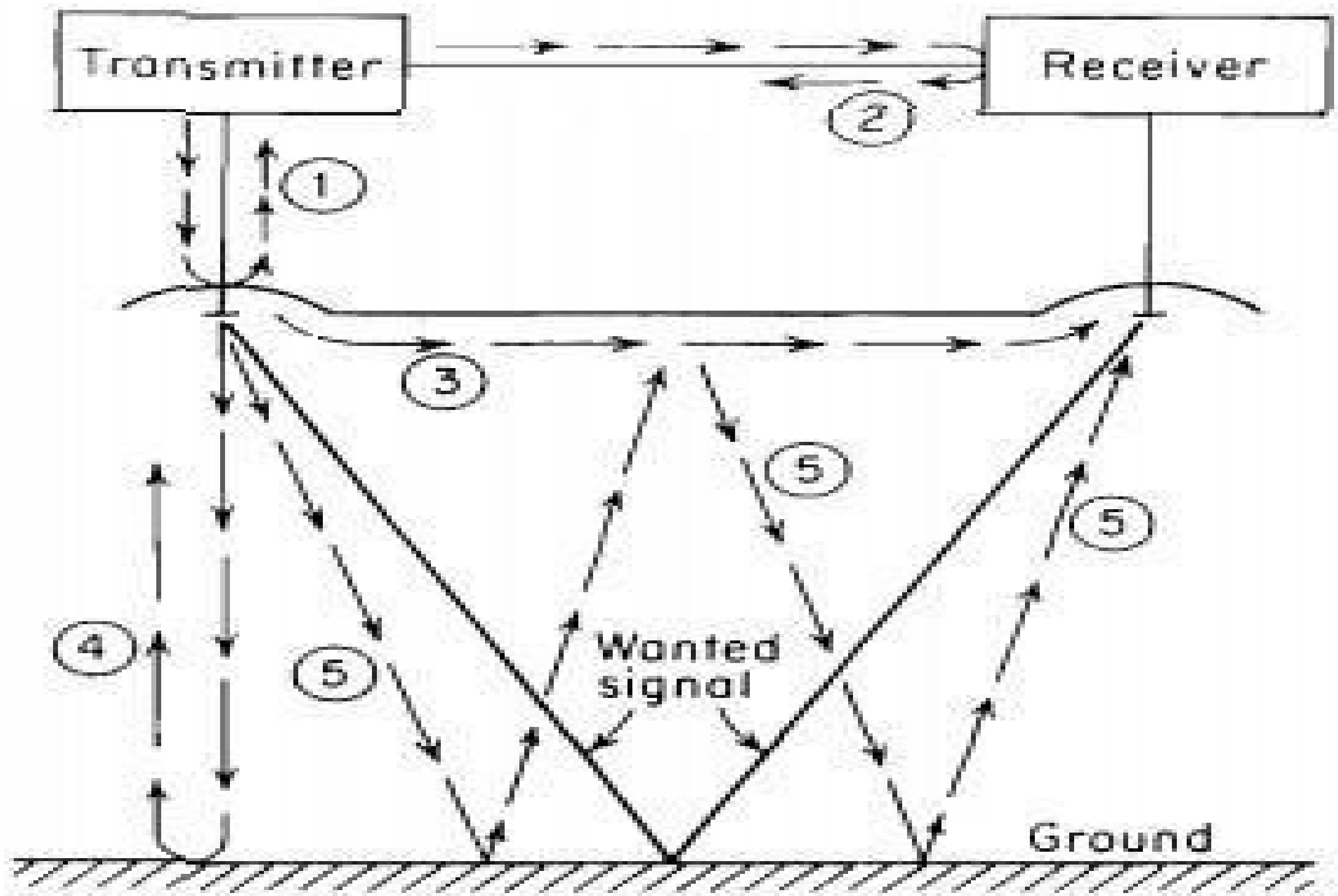
c = velocity of propagation. m/s   Δf = frequency excursion. Hz

- Since the output of the frequency counter N is an integer, the range will be an integral multiple of $c / 4\,\Delta f$ *and will give rise to a quantization error equal to*

$\delta R = c / 4\,\Delta f$

$\delta R\,(m) = 75 / \Delta f\,(MHz)$

Unwanted Signals



Unwanted Signals

•The Unwanted signals include 1.Transmitting Antenna impedance mismatch 2.Receiver poor mixer match.

3.Coupling between transmitter and receiver antennas

4.The interference due to power being reflected back to the transmitter

5. The double-bounce signal.

Sinusoidal Modulation

- If the CW carrier is frequency-modulated by a sine wave, the difference frequency obtained by heterodyning the returned signal with a portion of the transmitter signal may be expanded in a trigonometric series whose terms are the harmonics of the modulating frequency $\sin\left(2\pi f_0 t + \dfrac{\Delta f}{2 f_m} \sin 2\pi f_m t\right)$
- Assume the form of the transmitted signal to be where,

fo = carrier frequency
fm = modulation frequency
Δf = frequency excursion

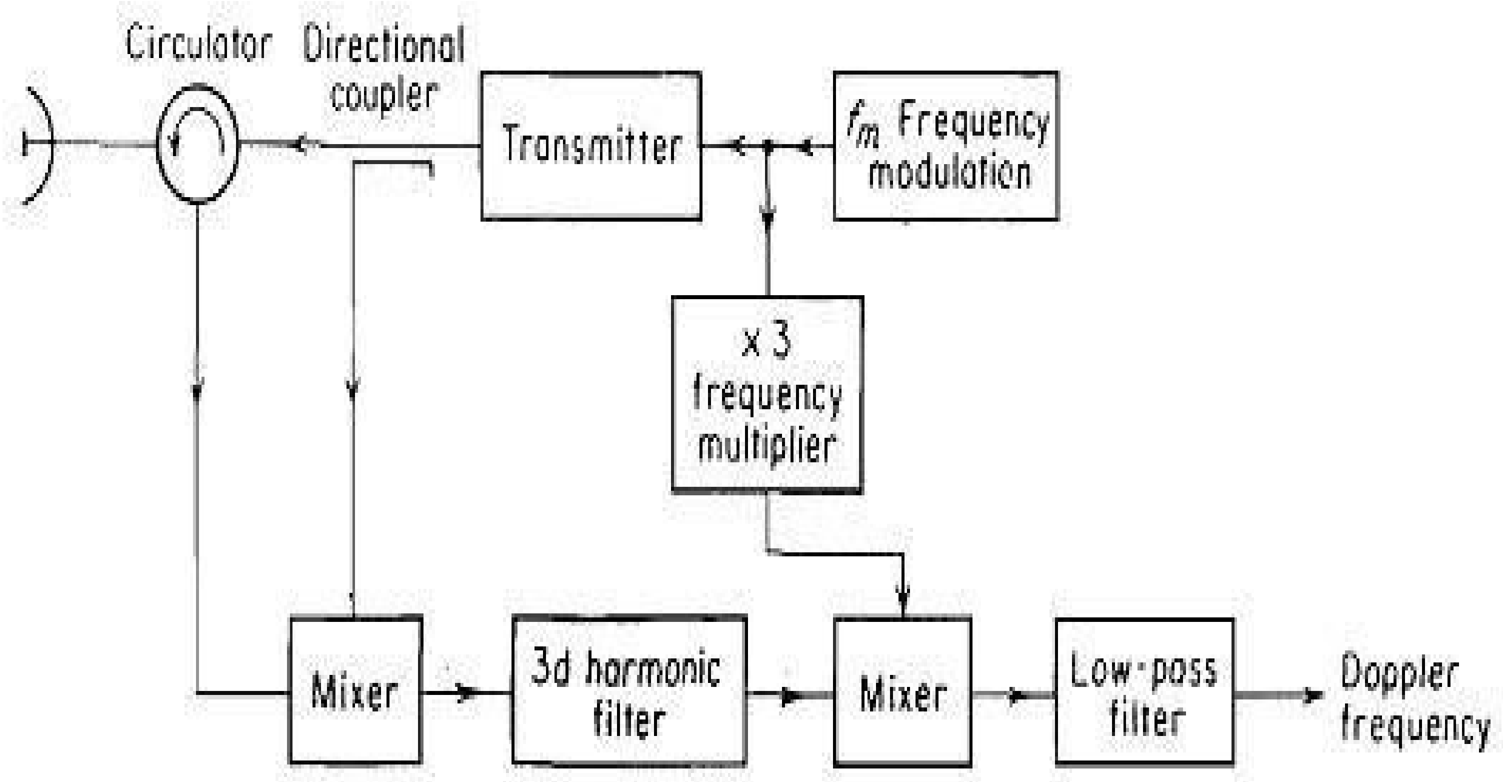
Sinusoidal Modulation

- The difference frequency signal may be

$$
\begin{aligned}
v_D = {} & J_0(D)\cos(2\pi f_d t - \phi_0) + 2J_1(D)\sin(2\pi f_d t - \phi_0)\cos(2\pi f_m t - \phi_m) \\
& - 2J_2(D)\cos(2\pi f_d t - \phi_0)\cos 2(2\pi f_m t - \phi_m) \\
& - 2J_3(D)\sin(2\pi f_d t - \phi_0)\cos 3(2\pi f_m t - \phi_m) \\
& + 2J_4(D)\cos(2\pi f_d t - \phi_0)\cos 4(2\pi f_m t - \phi_m) + 2J_5(D)\cdots
\end{aligned}
$$

where J0, J1, J2, etc = Bessel functions of first kind and order 0, 1, 2, etc., respectively
D = (*Δf / fm) sin 2π fm R0 /c*
R0 = distance to target at time t = 0 (distance that would have been measured if target
were stationary)
c = velocity of propagation
fd = doppler frequency shift
vr = relative velocity of target with respect to radar
ϕ0 = phase shift approxirnately equal to angular distance 2π *f0 R0 /c*
ϕm = phase shift approxirnately equal to 2π *fm R0 /c*

Sinusoidal Modulation (3rd Harmonic) Extraction



Multiple Frequency CW Radar

- The voltage waveforms of the two components of the transmitted signal *v1r and v2r, may* be written as

$v1r = sin\ (2\pi f1\ t + \varphi 1)$

$v2r = sin\ (2\pi f2\ t + \varphi 2)$

where ϕ1 and ϕ2 are arbitrary (constant) phase angles.

- The echo signal is shifted in frequency by the

dopp Signler emayffect The form of the dopplershifted

a

$$v_{1R} = \sin\left[2\pi(f_1 \pm f_{d1})t - \frac{4\pi f_1 R_0}{c} + \phi_1\right]$$

$$v_{2R} = \sin\left[2\pi(f_2 \pm f_{d2})t - \frac{4\pi f_2 R_0}{c} + \phi_2\right]$$

Multiple Frequency CW Radar

- Where, Ro = range to target at a particular time t = t0 (range that would be measured if target were not moving)
- *fd1 = doppler frequency shift associated with frequency f1*
- *fd2 = doppler frequency shift associated with frequency*

f2

- Since the two RF frequencies *f1 , and f2 are approximately the same the doppler frequency* shifts *fd1 and fd2 are approximately equal to one another. Therefore*
- *fd1 = fd2 = fd*

Multiple Frequency CW Radar

- The receiver separates the two components of the echo signal and heterodynes each received signal component with the corresponding transmitted waveform and extra

com

$$v_{1D} = \sin\left(\pm 2\pi f_d t - \frac{4\pi f_1 R_0}{c}\right)$$

$$v_{2D} = \sin\left(\pm 2\pi f_d t - \frac{4\pi f_2 R_0}{c}\right)$$

Multiple Frequency CW Radar

- The phase difference between these two components is

$$\Delta\phi = \frac{4\pi(f_2 - f_1)R_0}{c} = \frac{4\pi\,\Delta f R_0}{c}$$

$$R_0 = \frac{c\,\Delta\phi}{4\pi\,\Delta f}$$

Multiple Frequency CW

- There is a limit to the value of Δf, since $\Delta\phi$ cannot be greater than 2π radians if the range is to remain unambiguous

- $R_{unamb} = c / 2\Delta f$
- Δf must be less than $c/2 R_{unamb}$
- When Δf is replaced with Pulse Repetition Rate gives

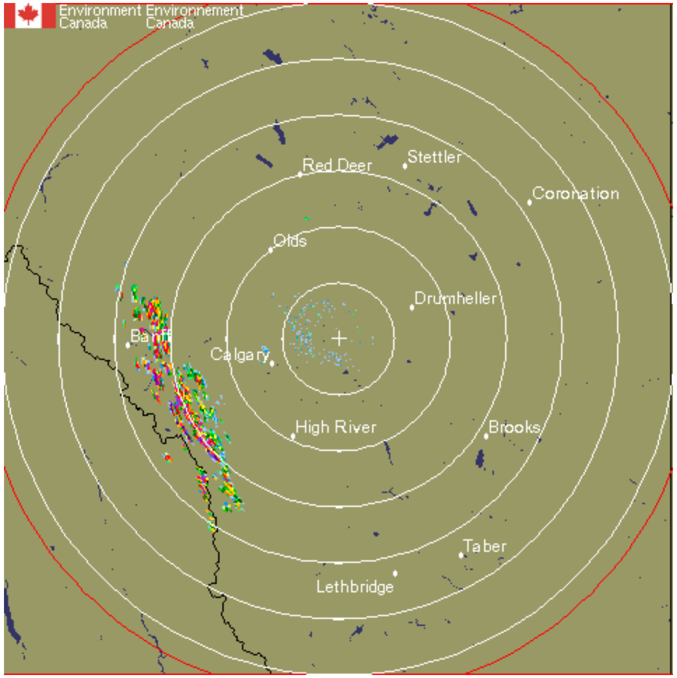
Maximum Unambiguous Range of a Pulse Radar.

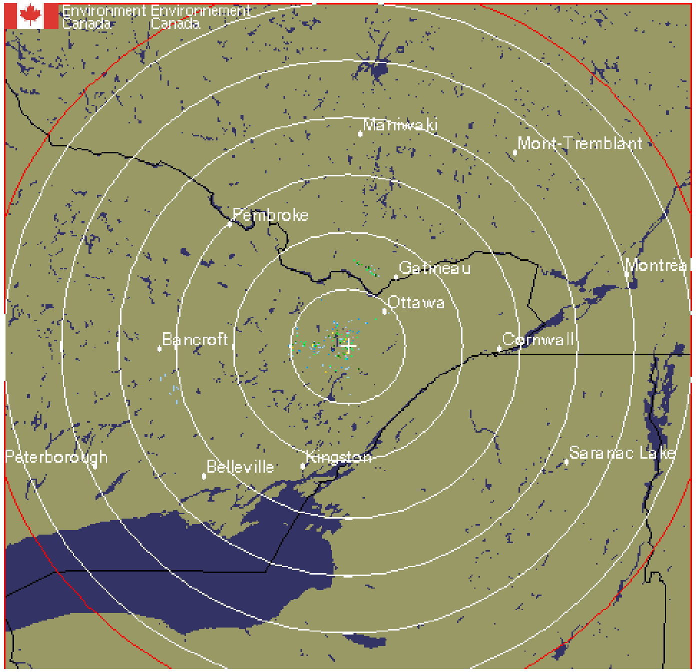
UNIT III

Moving Target Indicator Radar (MTI)

Clutter is the term used for radar targets which are not of interest to the user.

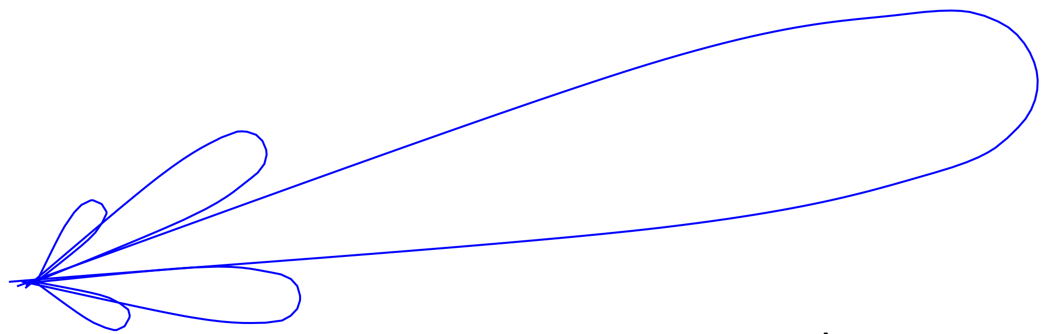
Clutter is usually caused by static objects near the radar but sometimes far away as well:





Moving Target Indicator Radar (MTI)

Sometimes clutter can be caused by sidelobes in the antenna pattern or a poorly adjusted antenna



n n

In any case it is desirable to eliminate as mucnh clutter as possible

n

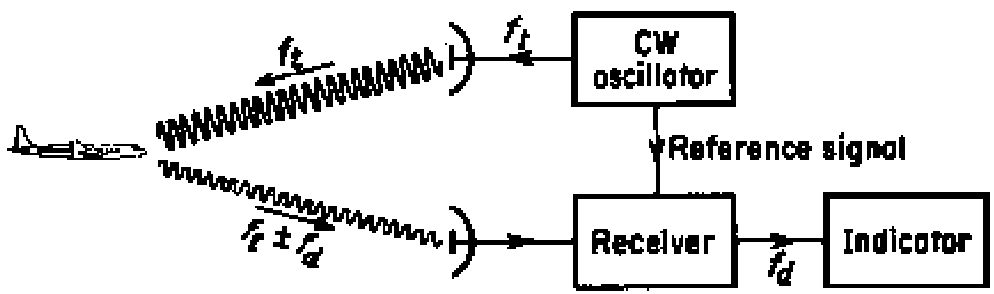
Moving Target Indicator Radar (MTI)

This is done by using the fact that the desired target is usually moving relative to the radar and thus causes a Doppler shift in the return signal.

The Doppler shift can also be used to determine the relative speed of the target.

n

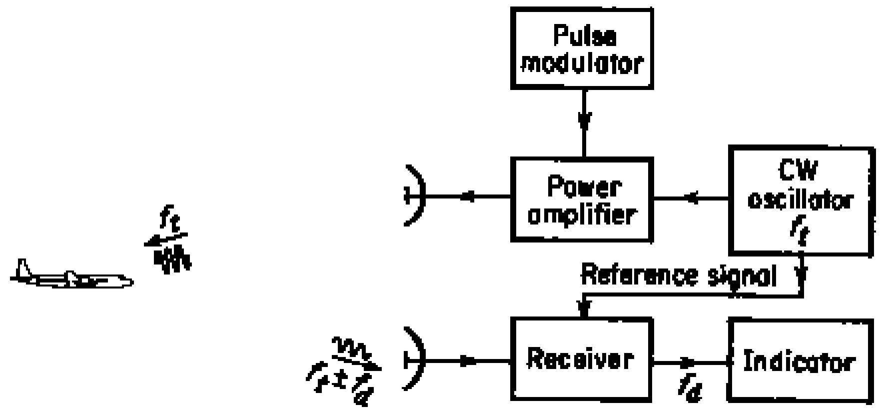
n



(a)

Moving Target Indicator Radar (MTI)

The simple CW example can be modified to incorporate pulse modulation



(b)

Note that the same oscillator is used transmission and demodulation of the return

Thus the return is processed coherently

i.e. the phase of the signal is preserved

Moving Target Indicator Radar (MTI)

The transmitted signal is

$$V_{ref} = A_2 \sin 2\pi f_t t$$

and the received signal is

$$V_{echo} = A_3 \sin\left[2\pi(f_t \pm f_d)t - \frac{4\pi f_t R_0}{c}\right]$$

these are mixed and the difference is extracted

n

$$V_{diff} = A_4 \sin\left[2\pi f_d t - \frac{4\pi f_t R_0}{c}\right]$$

n

This has two components, one is a sine wave at Doppler frequency, the other is a phase shift which depends on the range to the tar^{n}get, R_0

Moving Target Indicator Radar (MTI)

$$V_{diff} = A_4 \sin\left[2\pi f_d t - \frac{4\pi f_t R_0}{c}\right]$$

Note that for stationary targets $f_d = 0$ so V_{diff} is constant

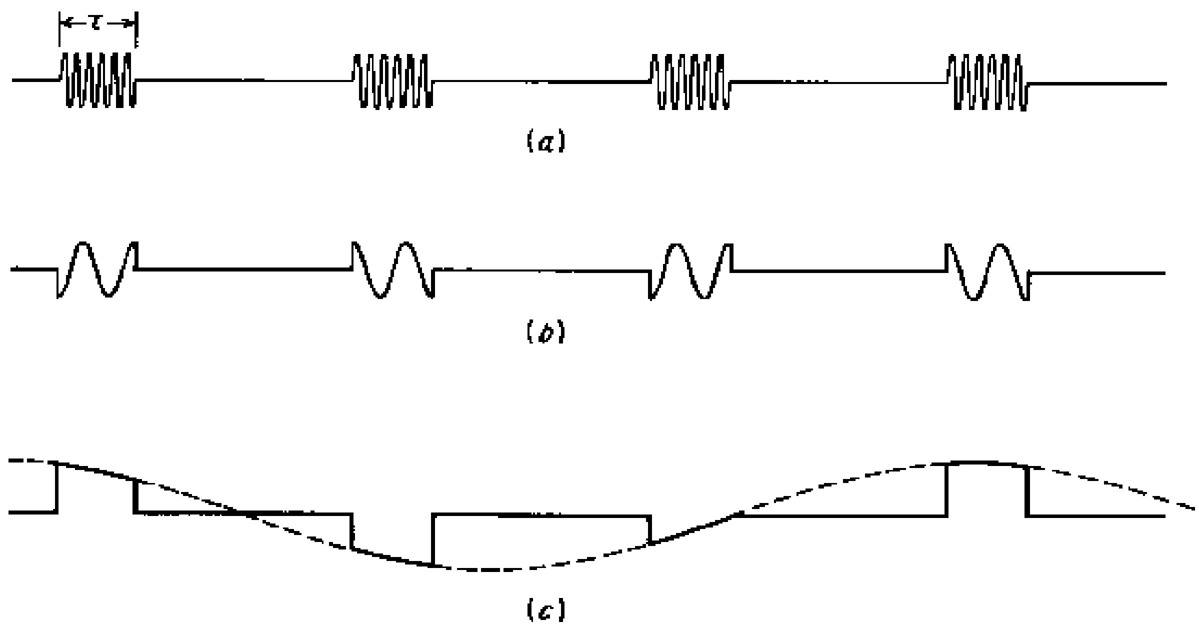
Depending on the Doppler frequency one two situations will occur

n

n

$f_d > 1/\tau$

$f_d < 1/\tau$



Moving Target Indicator Radar (MTI)

Note that for a pulse width of 1µs, the dividing line is a Doppler shift of 1 MHz.

If the carrier frequency is 1 GHz, this implies a relative speed of

30,000 m/s

Thus all terrestrial radars operate in a sampled mode and thus are subject to the rules of sampled signals

n

n

e.g. Nyquist's criterion

We shall also see that we can use Discrete Sample Processing (DSP) to handle some of the problems

n

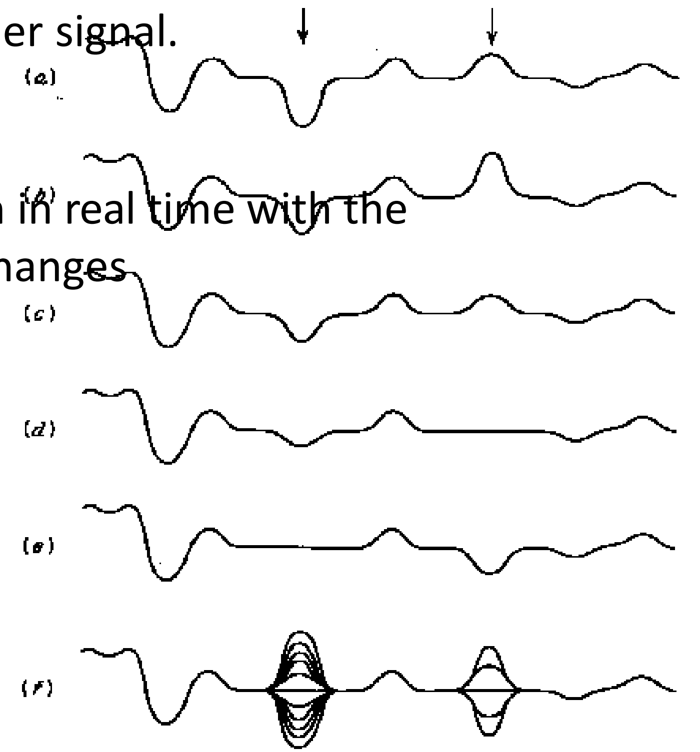
n

Moving Target Indicator Radar (MTI)

Looking a successive oscilloscope displays of radar receiver output we see:

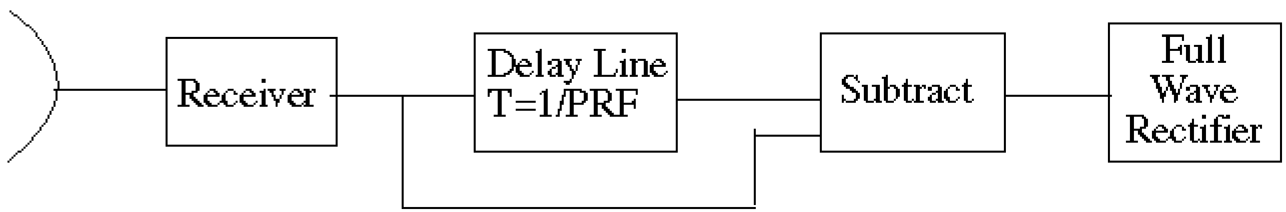
At the ranges of the two targets, the return ampliude is varying as the radar samples the (relatively) slow Doppler signal.

The bottom trace shows what would be seen in real time with the moving targets indicated by the amplitude changes



Moving Target Indicator Radar (MTI)

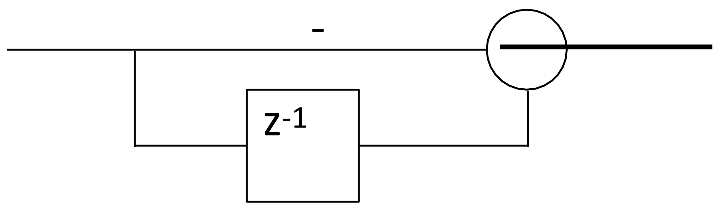
We usually want to process the information automatically. To do this we take advantage of the fact that the amplitudes of successive pulse returns are different:



n

OR

n



Moving Target Indicator Radar (MTI)

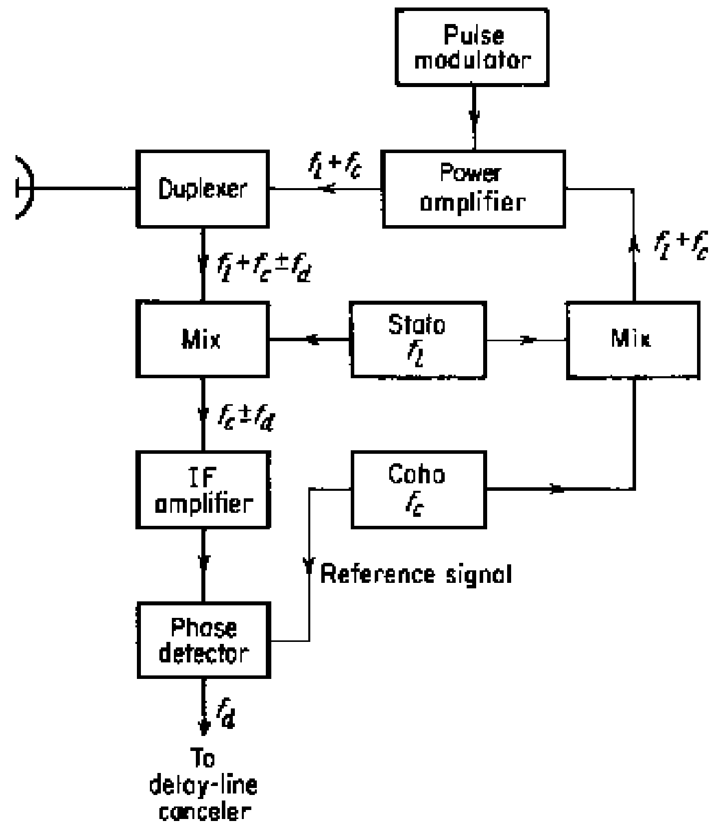
MTI Radar Block Diagrams

MOPA (master oscillator, power amplifier)

Power amplifiers: Klystron

TWT (Travelling wave tube) Solid State

(Parallel)



Moving Target Indicator Radar (MTI)

One of the problems with MTI in pulsed radars is that magnetrons are ON/OFF devices.

i.e. When the magnetron is pulsed it starts up with a random phase and is thus its ouput is not coherent with the pulse before it. Also it can not provide a reference oscillator to mix with the received signals.

n

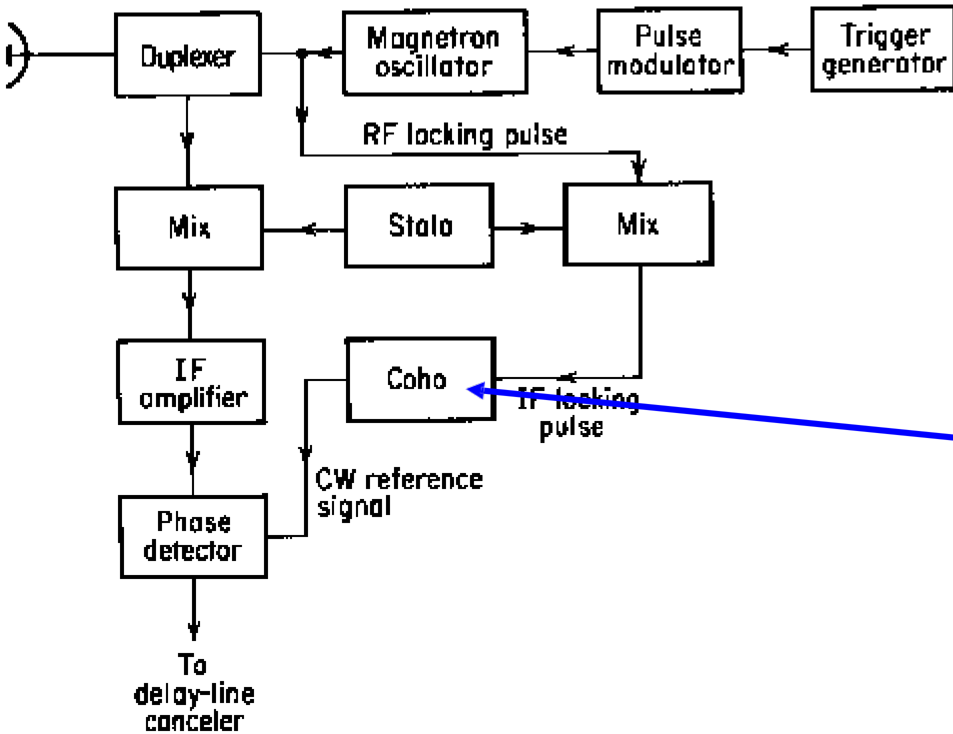
n

Therefore some means must be provided to maintain the coherence (at least during a single pulse period)

n

n

Moving Target Indicator Radar (MTI)



n n

PLL

n

n

Moving Target Indicator Radar (MTI)

The notes have a section on various types of delay line cancellers.

This is a bit out of date because almost all radars today

use digitized data and implementing the required delays is relatively trivial but it also opens up much more complex processing possibilities

n n

n

n

Moving Target Indicator Radar (MTI)

The Filtering Characteristics of a Delay Line Canceller

The output of a single delay canceller is:

$$v_1 - v_2 = 2k \sin \boxed{\pi f_d T} \cos\left[2\pi f_d\left(t - \frac{T}{2}\right) - \phi_0\right]$$

This will be zero whenever $\pi f_d T$ is 0 or a multiple of π

The speeds at which this occurs are called the blind^n

speeds of the radar

n

.

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

where n is 0,1,2,3,…

Moving Target Indicator Radar (MTI)

If the first blind speed is to be greater than the highest expected radial speed the λf_p must be large

large λ means larger antennas for a given beamwidth

large f_p means that the unambiguous range will be quite$_n$small

n

So there has to be a compromise in the design of an MTI radar

n

n

Moving Target Indicator Radar (MTI)

The choice of operating with blind speeds or ambiguous ranges depends on the application

Two ways to mitigate the problem at the expense of increased complexity are:

n

a. operating with multiple prfs

b. operating with multiple carrier frequencies

n

n

n

Moving Target Indicator Radar (MTI)

Double Cancellation:

Single cancellers do not have a very sharp cutoff at the nulls which limits their rejection of clutter

(clutter does not have a zero width spectrum)

n

n

Adding more cancellers sharpens the nulls

n

n

Moving Target Indicator Radar (MTI)

Double Cancellation:

There are two implementations:

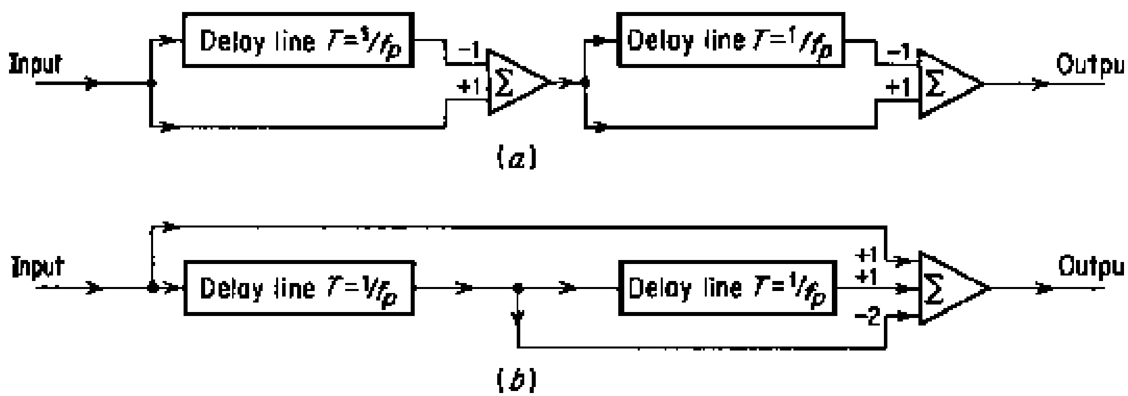


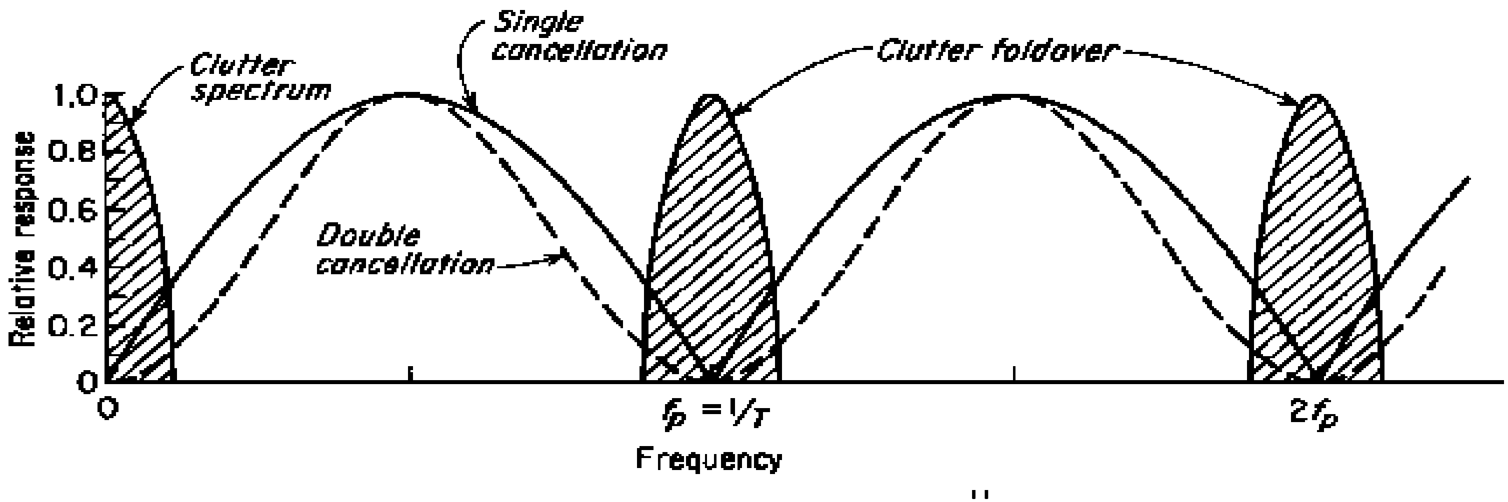
Figure 4.9 (*a*) Double-delay-line canceler; (*b*) three-pulse canceler.

These have the same frequency response: which is the square of the single canceller response

$$|v| = 4\sin^2(\pi f_d T)$$

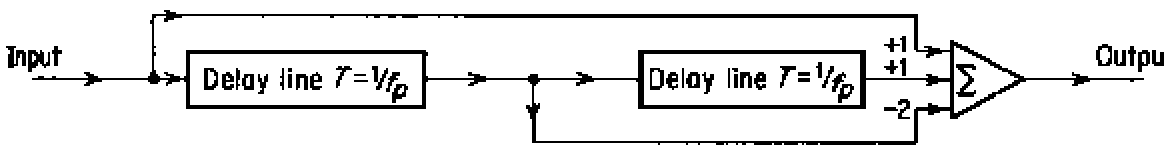
Moving Target Indicator Radar (MTI)

Double Cancellation:



Moving Target Indicator Radar (MTI)

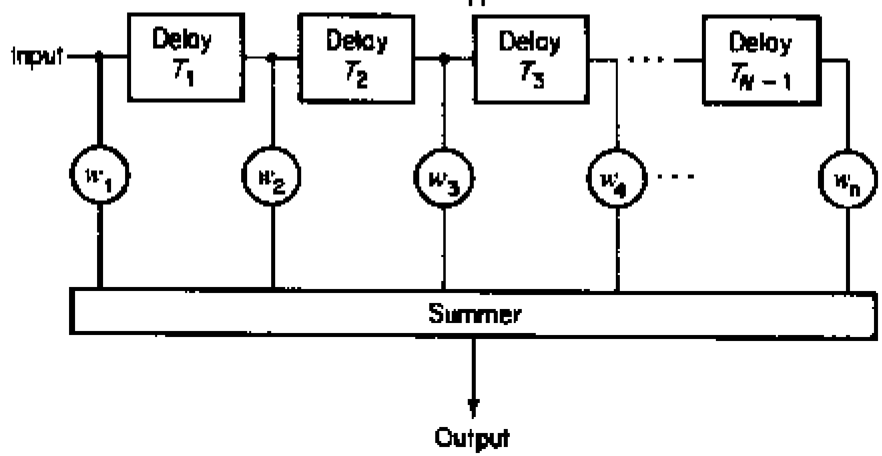
Transversal Filters



These are basically a tapped delay line with the taps summed at the output

n

n



Moving Target Indicator Radar (MTI)

Transversal Filters

To obtain a frequency response of $\sin^n \pi f_d T$,
the taps must be binomially weighted i.e.

n

n

$$w_i = (-i)^{i-1} \frac{n!}{(n-i+1)!(i-1)!} \;\; ; \quad i=1,2,3....n+1$$

..

n

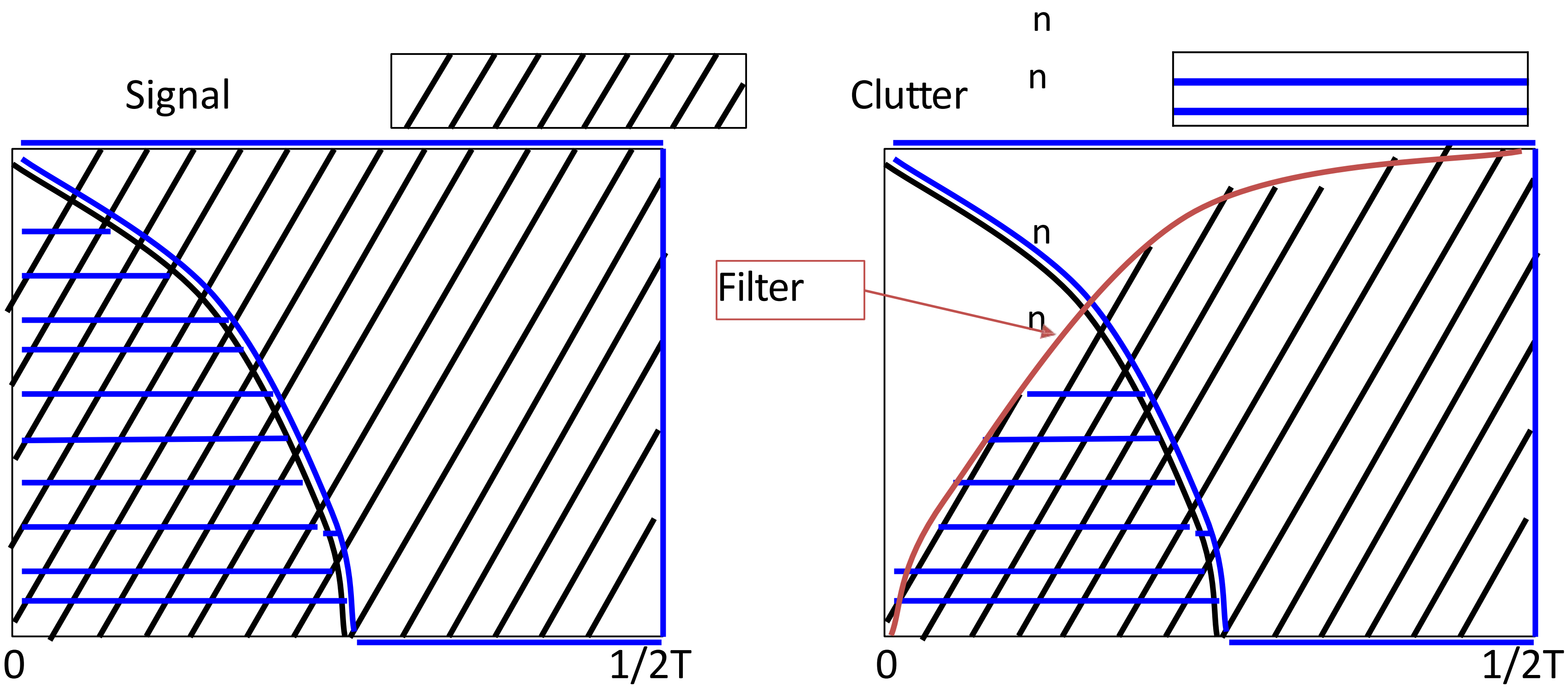
Moving Target Indicator Radar (MTI)

Filter Performance Measures

<u>MTI Improvement Factor</u>, I_C

$$I_C = \frac{(S/C)_{out}}{(S/C)_{in}}$$

Note that this is averaged over all Doppler frequencies



Moving Target Indicator Radar (MTI)

Filter Performance Measures

Clutter Attenuation ,C/A

The ratio of the clutter power at the input of the canceler

to the clutter power at the output of the canceler n

n

It is normalized, (or adjusted) to the signal attenuation of the canceler.

i.e. the inherent signal attenuation of the canceler n is ignored

n

Moving Target Indicator Radar (MTI)

Transversal Filters with Binomial Weighting with alternating sign

Advantages:

Close to optimum for maximizing the Clutter improvement factor

n

Also close to maximizing the Clutter Attenuation n

C_{in}/C_{out}

$$I_C = \frac{(S/C)_{out}}{(S/C)_{in}}$$

n

Moving Target Indicator Radar (MTI)

Transversal Filters with Binomial Weighting with alternating sign

Disadvantage:

As n increases the $\sin^n$ filter cuts off more and more of the spectrum around DC and multiples of PRF

n

This leads to wider blind speed zones and hence loss$_n$ of legitimate targets.

n

n

% of targets rejected	n pulse canceler
20	2
35	3
48!	4

Moving Target Indicator Radar (MTI)

The ideal MTI filter should reject clutter at DC and th PRFs but give a flat pass band at all other frequencies.

The ability to shape the frequency response depends to a large degree on the number of pulses used. The more pulses, the more flexibility in the filter design.

Unfortunately the number of pulses is limited by the scnan rate and the banetaemmwaidth.

n

Note that not all pulses are useful:

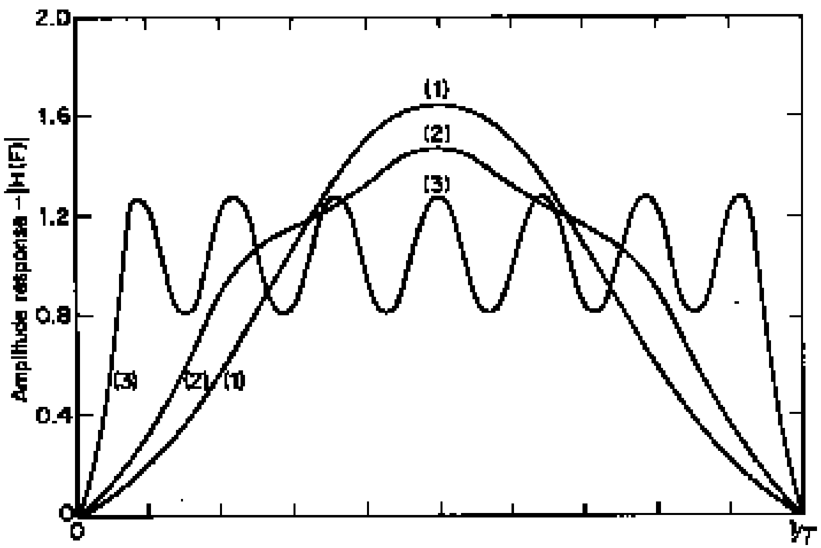
n

The first n-1 pulses in an n pulse canceler are not useful

n

Moving Target Indicator Radar (MTI)

Some other transversal filter responses are shown:



n

(1) 3 pulse canceler

(2) 5 pulse “optimum” filter which maximizes I_C

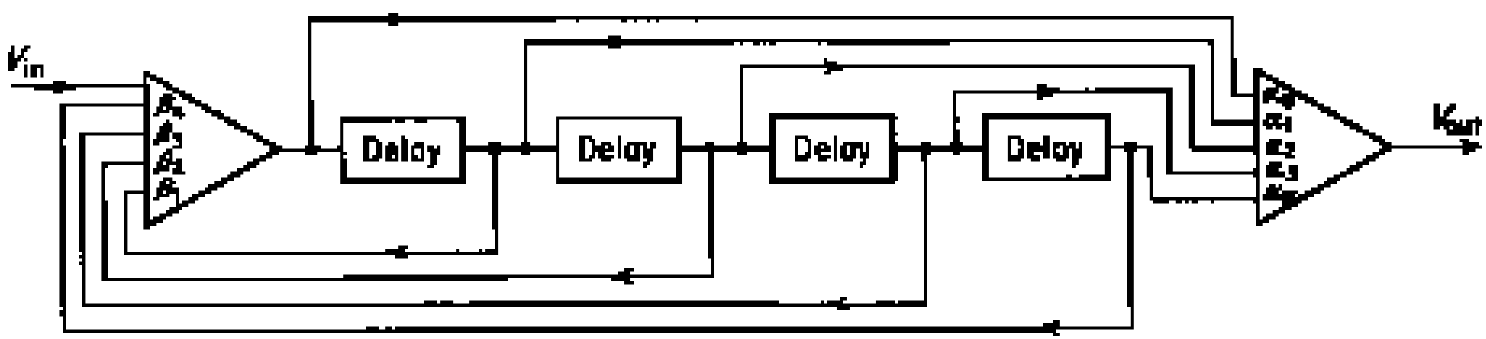
(3) 15 pulse Chebyshev filter

Moving Target Indicator Radar (MTI)

Feed forward (finite impulse response or FIR) filters have only poles (one per delay)

More flexibility in filter design can be obtained if we use recursive or feedback filters (also known as infinite impulse response or IIR filters)

These have a zero as well as a pole per delay and thus have twice as many variables to play with



Moving Target Indicator Radar (MTI)

IIR filters can be designed using standard continuous-time filter techniques and then transformed into the discrete form using z transforms

Thus almost any kind of frequency response can be obtained with these filters.

They work very well in the steady state case but unfortunately their transient response is not very good. A large pulse input can cause the filter to “ring” and thus miss desired targets.

Since most radars use short pulses, the filters are almost always in a transient state

Moving Target Indicator Radar (MTI)

Multiple PRFs

An alternative is to use multiple PRFs because the blind speeds (and hence the shape of the filter response) depends on the PRF and, combining two or more PRFs offers an opportunity to shape the overall response.

Moving Target Indicator Radar (MTI)

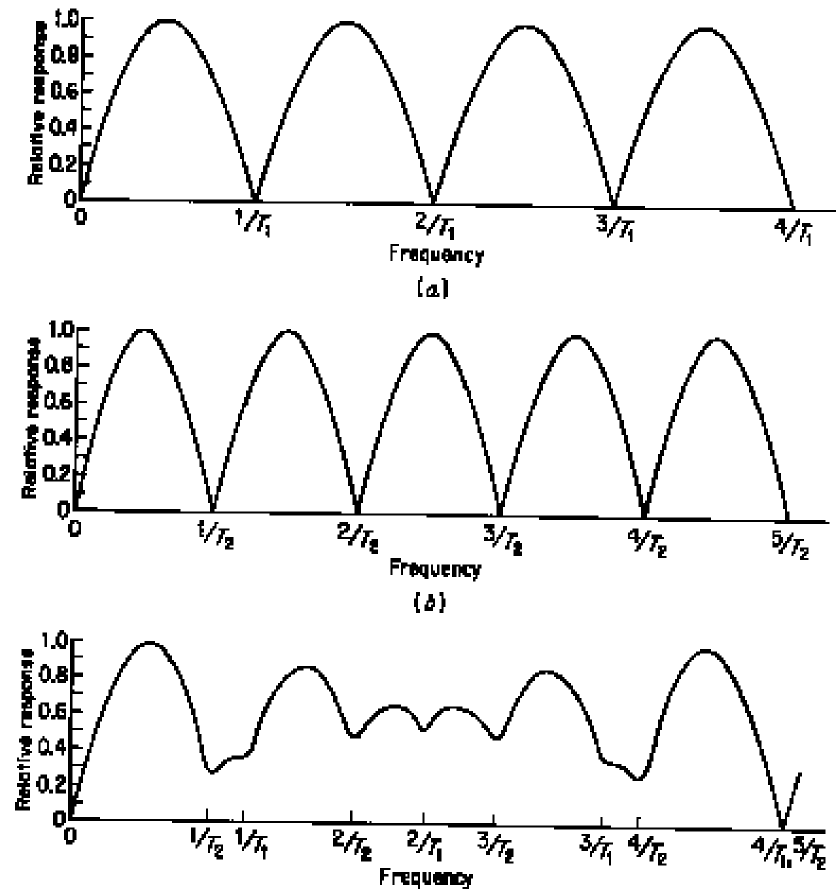
Multiple PRFs: Example

Two PRFs

Ratio 4/5

First blind speed is at

$5/T_1$ or $4/T_2$



Moving Target Indicator Radar (MTI)

Multiple PRFs: Example

Four PRFs

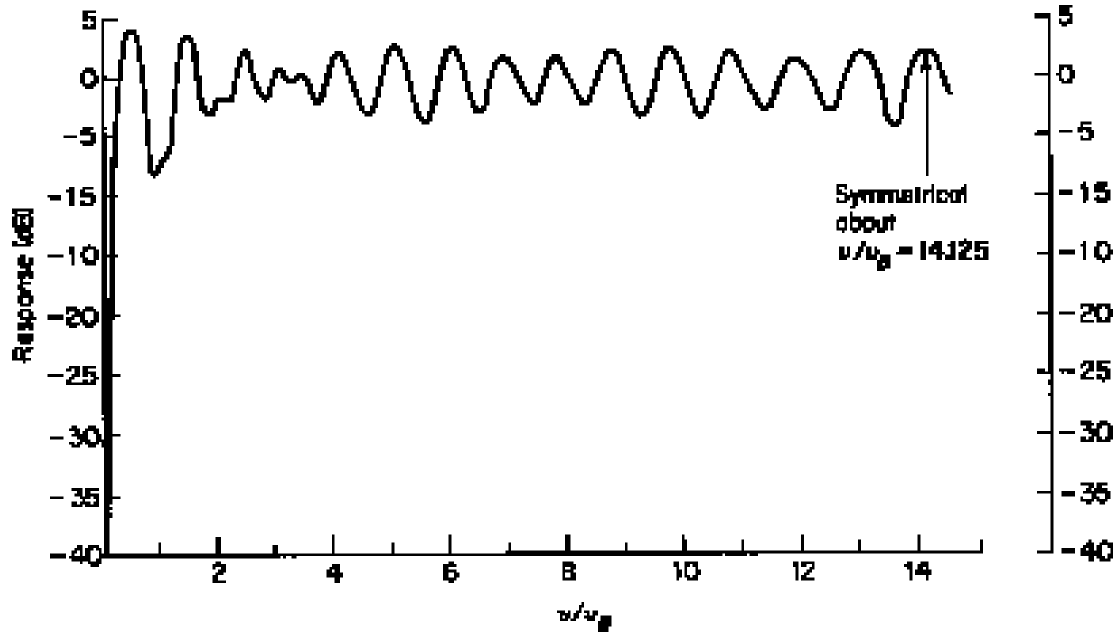
Ratio 25/30/27/31

First blind speed is at about

$28.25/T_{AV}$

where T_{AV}

is the average period of the four PRFs



Moving Target Indicator Radar (MTI)

Multiple PRFs: Example

Calculation of First Blind Speed

if the relationship between the Pulse Periods is

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

and v_B is the first blind speed of a PRF with average period

$$T_{AVE} = \frac{1}{N}\left[T_1 + T_2 + \cdots T_N\right]$$

The first blind speed is

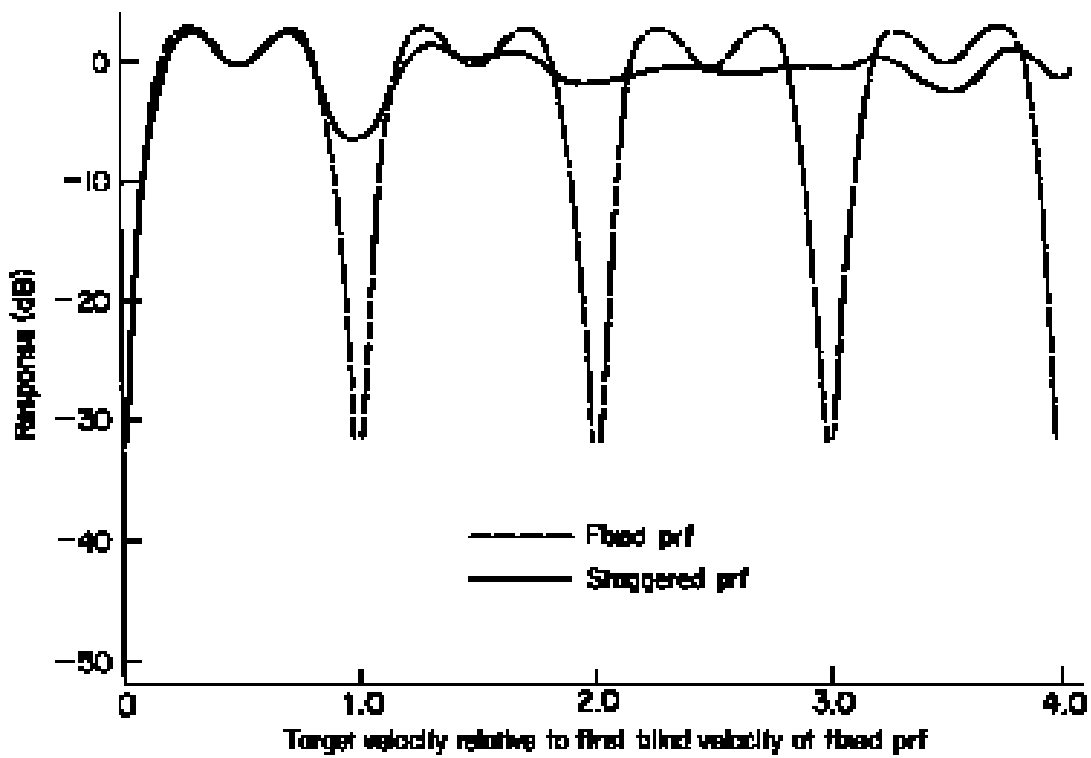
$$v_1 = v_B \left[\frac{n_1 + n_2 + \cdots n_N}{N}\right]$$

Moving Target Indicator Radar (MTI)

Multiple PRFs can also be used with transversal filters

Example

5 pulse canceler with 4 staggered PRFs

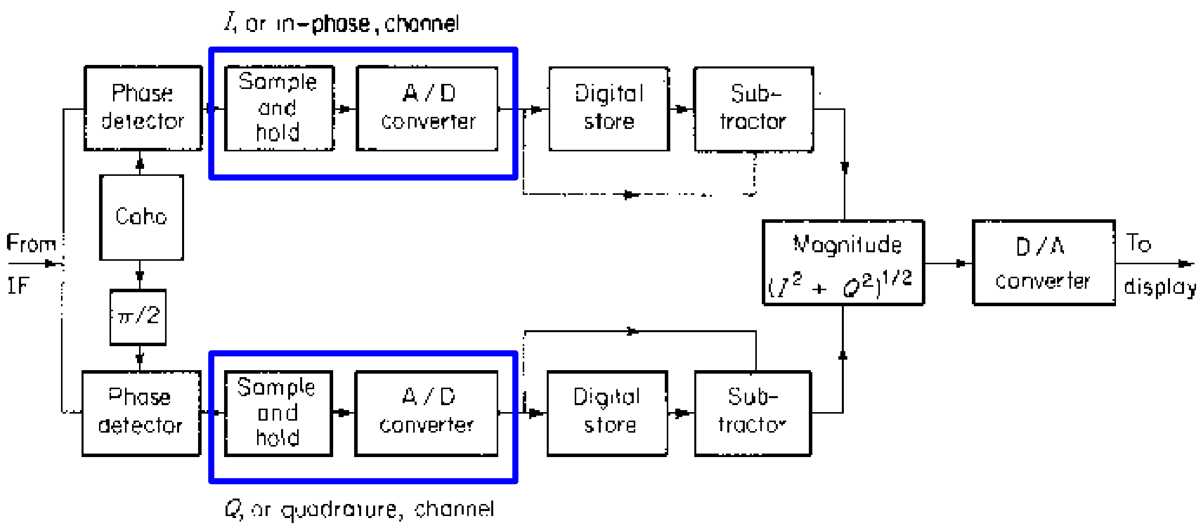


Moving Target Indicator Radar (MTI)

Digital (or Discrete) Signal Processing (DSP)

These days almost all radar signal processing is done using DSP.

The down-converted signal is sampled by an A/D converter as follows:



Note:

The quadrature channel removes blind phases

Moving Target Indicator Radar (MTI)

- Advantages of DSP
  - greater stability
  - greater repeatability
  - greater precision
  - greater reliability
  - easy to implement multiple PRFs
  - greater flexibility in designing filters
  - gives the ability to change the system parameters dynamically

Moving Target Indicator Radar (MTI)

Digital (or Discrete) Signal Processing (DSP)

Note that the requirements for the A/D are not very difficult to meet with today's technology.

Sampling Rate

Assuming a resolution (R_{res}) of 150m, the received signal has to be sampled at intervals of $c/2R_{res}$ = 1µs or a sampling rate of 1 MHz

Memory Requirement

Assuming an antenna rotation period of 12 s (5rpm) the storage required would be only 12 Mbytes/scan.

Moving Target Indicator Radar (MTI)

Digital (or Discrete) Signal Processing (DSP)

<u>Quantization Noise</u>

The A/D introduces noise because it quantizes the signal

The Improvement Factor can be limited by the quantization noise

the limit being:

$$I_{QN} \approx 20\log\left[(2^N - 1) \quad 0.75\right] \qquad \sqrt{}$$

This is approximately 6 dB per bit

A 10 bit A/D thus gives a limit of 60 dB

In practice one or more extra bits to achieve the desired performance

Moving Target Indicator Radar (MTI)

Digital (or Discrete) Signal Processing (DSP)

<u>Dynamic Range</u>

This is the maximum signal to noise ratio that can be handled by the A/D without saturation

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

N= number of bits

k=rms noise level divided by the quantization interval the larger k the lower the dynamic range

but k<1 results in reduction of sensitivity

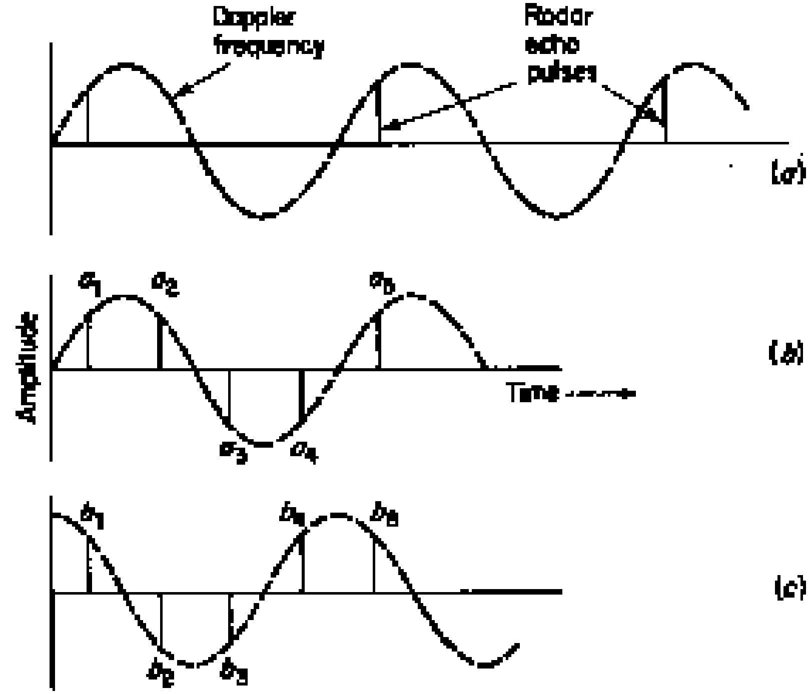
Note: A 10 bit A/D gives a dynamic range of 45.2dB

Moving Target Indicator Radar (MTI)

Blind Phases

If the prf is double the Doppler frequency then every othyer pair of samples cane be the same amplitude and will thus be filtered out of the signal.

By using both inphase and quadrature signals, blind phases can be eliminated

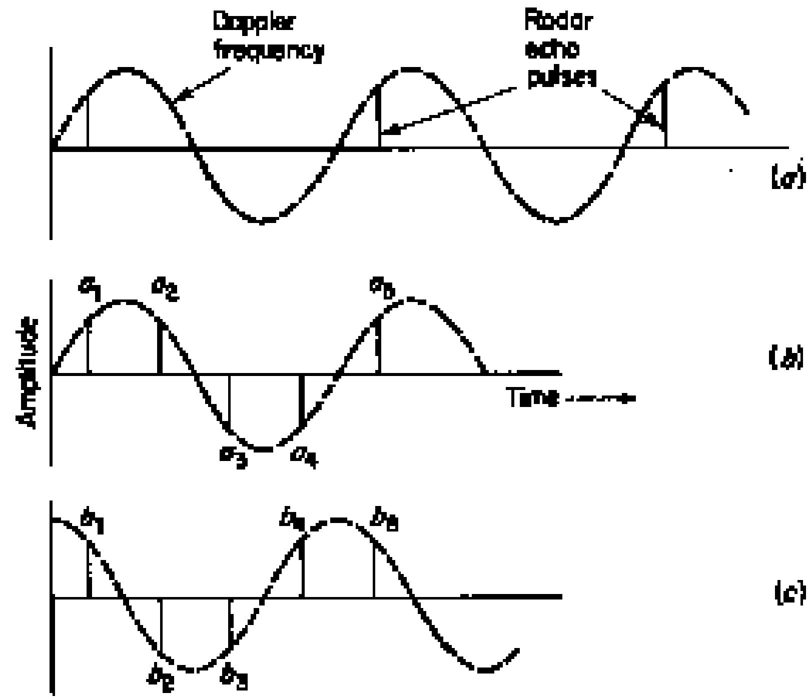


Moving Target Indicator Radar (MTI)

Blind Phases

If the prf is double the Doppler frequency then every other pair of samples can be the same amplitude and will thus be filtered out of the signal. (loss of 2.8dB and 13.7dB for P_d of 0.5 and 0.9 respectively)

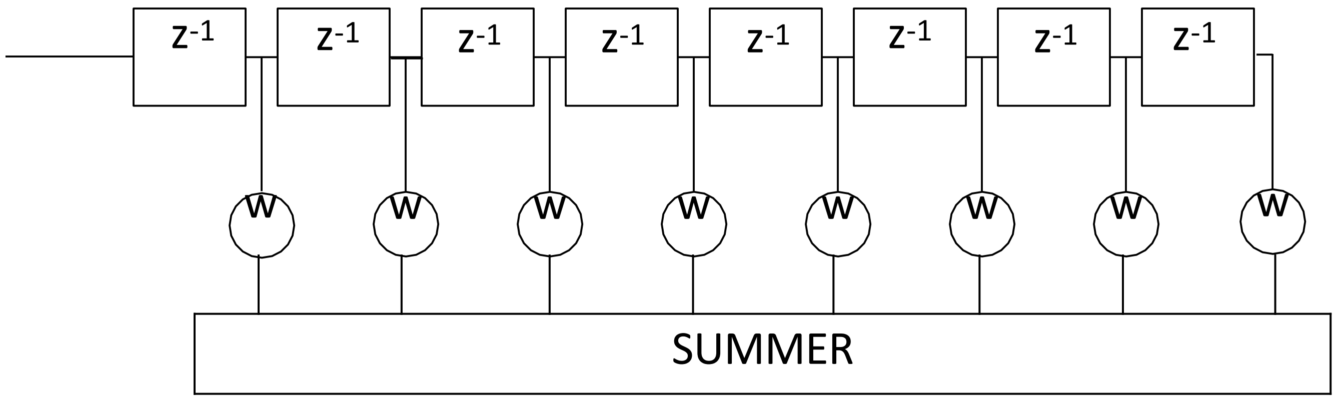
By using both inphase and quadrature signals, blind phases can be eliminated



Moving Target Indicator Radar (MTI)

Digital Filter Banks and FFT

Example: Transversal Filter with 8 delay elements:



If the weights are set to:

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

i= 1,2,3…N and k is an index from 0 to N-1

Moving Target Indicator Radar (MTI)

The impulse response of this filter is:

$$h_k(t) = \sum_{i=1}^{N} \delta\left[t - (i-1)T\right] e^{-j2\pi(i-1)k/N}$$

And from the Fourier transform its frequency response is

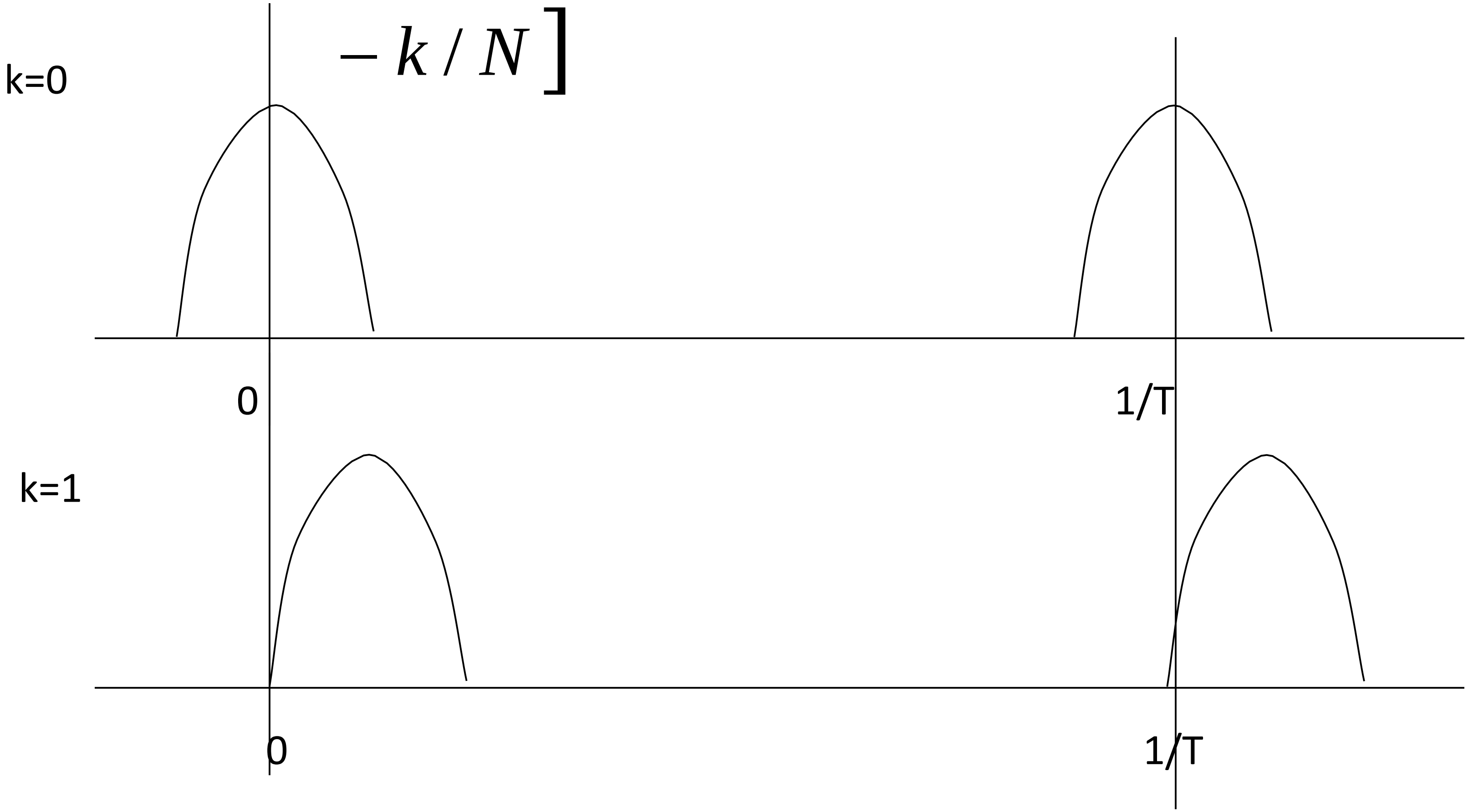
$$H_k(f) = e^{-j2\pi fT} \sum_{i=1}^{N} e^{j2\pi(i-1)\left[fT - k/N\right]}$$

The magnitude of the response is

$$\left|H_k(f)\right| = \frac{\sin\left[\pi N(fT - k/N)\right]}{\sin\left[\pi(fT - k/N)\right]}$$

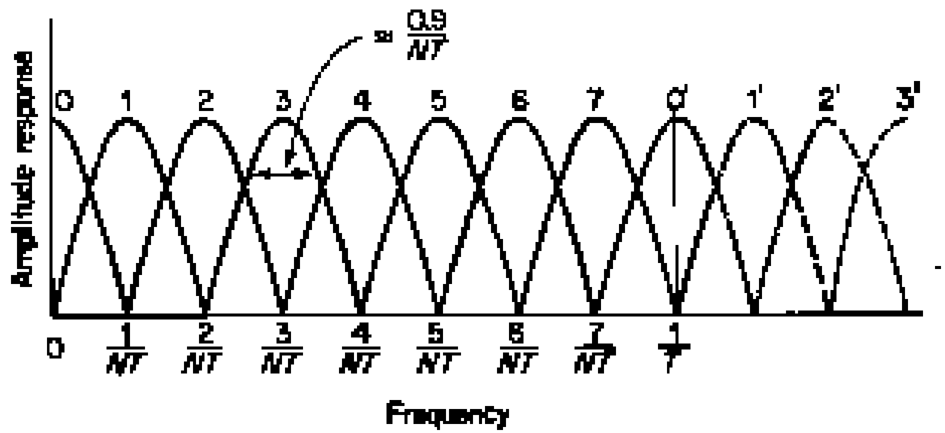
Moving Target Indicator Radar (MTI)

$$\left|H_k(f)\right| = \frac{\sin\left[\pi N\left(fT - k/N\right)\right]}{\sin\left[\pi\left(fT - k/N\right)\right]}$$



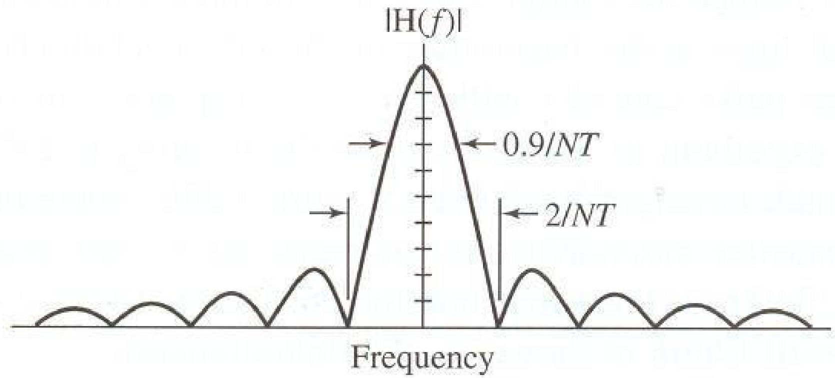
Moving Target Indicator Radar (MTI)

The response for all eight filters is:



Moving Target Indicator Radar (MTI)

The actual response for this filters is:



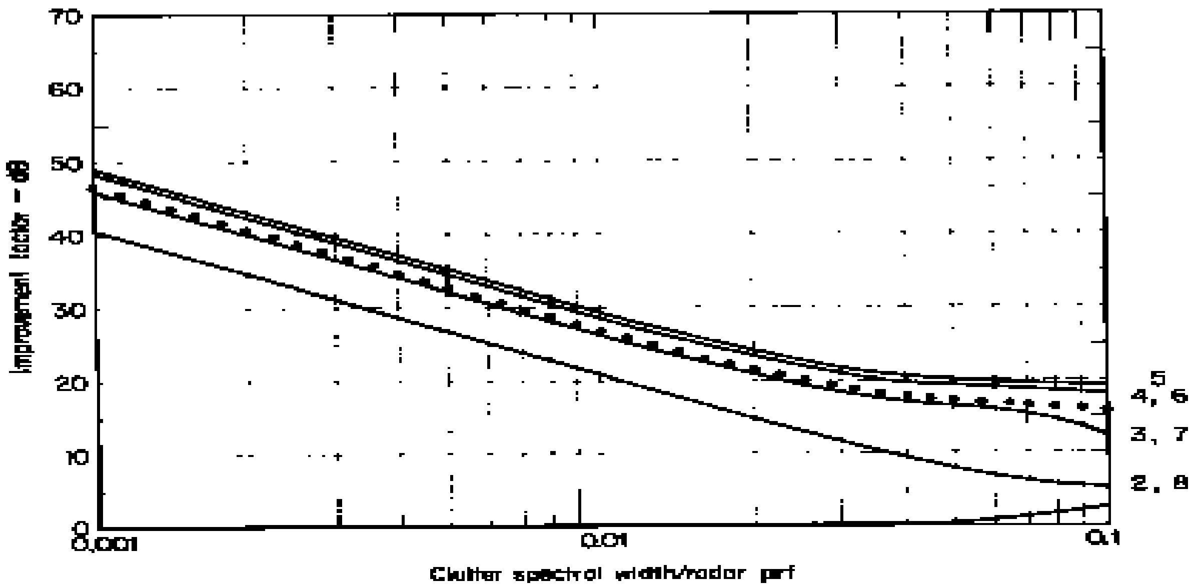
Which is sin (Nx)/sin(x)

The sidelobes of this filter are quite large (13dB below peak) and so it is not an ideal implementation

Moving Target Indicator Radar (MTI)

Other options are:

Uniform weighting and Chebyshev weights



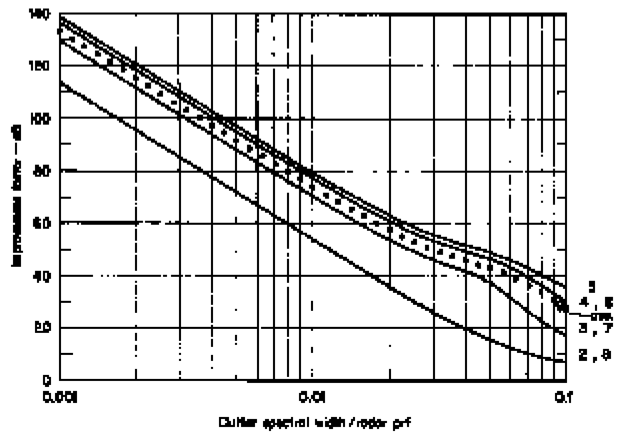
Clutter Improvement with Uniform weighting

(Filter Bank Only)

Moving Target Indicator Radar (MTI)

Filter Banks can also be preceded by cancelers

In the following cases a 3 pulse canceler

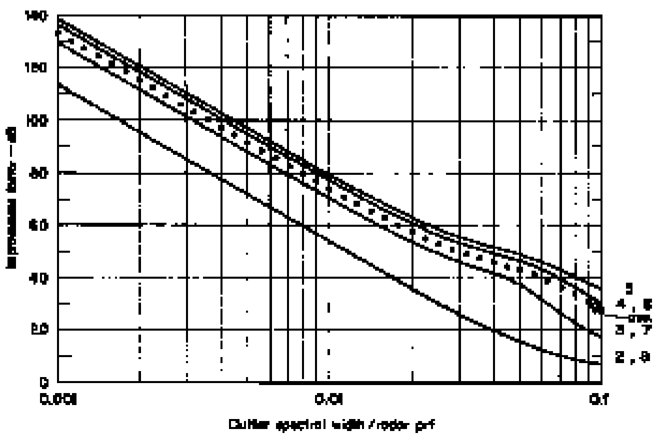


(a)

Moving Target Indicator Radar (MTI)

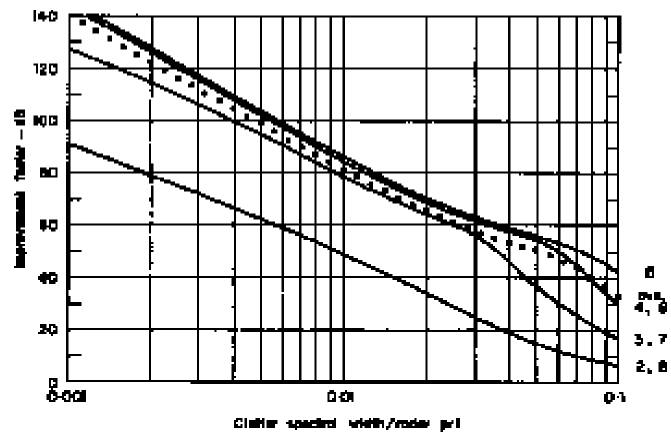
Filter Banks can also be preceded by cancelers

In the following cases a 3 pulse canceler is used ahead of an 8 pulse Doppler Filter Bank



(a)

Uniform

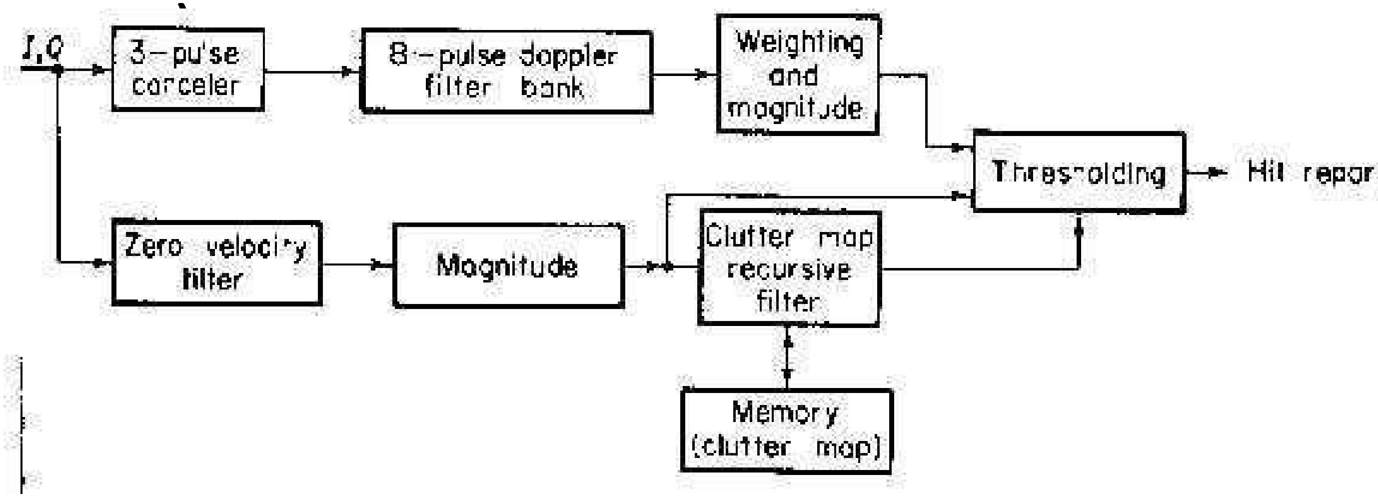


(b)

Chebyschev

Moving Target Indicator Radar (MTI) MTD (Moving Target Detector)

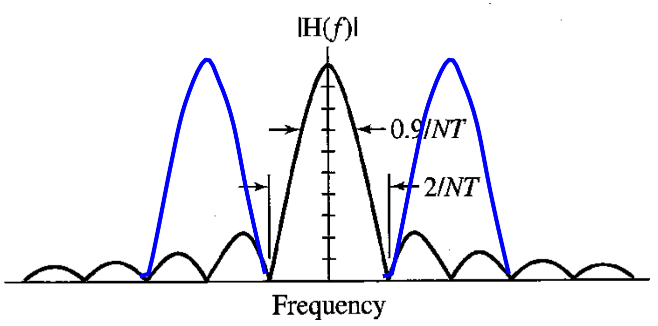
Example: ASR (Airport`Surveillance Radar
)



Moving Target Indicator Radar (MTI) MTD (Moving Target Detector)

Example: ASR (Airport`Surveillance Radar)

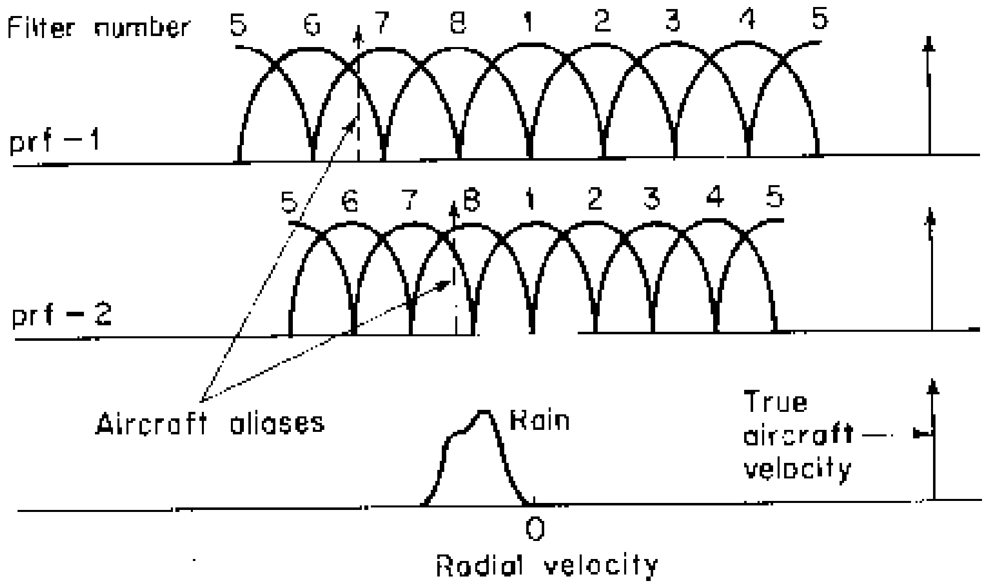
After the filter bank the doppler filter outputs are weighted to reduce the effects of the sidelobes in the filter



The outputs of the filters are modified by subtracting 25% of the outputs of the filters on either side.

Moving Target Indicator Radar (MTI)
MTD (Moving Target Detector)

Example: ASR (Airport`Surveillance Radar)



Moving Target Indicator Radar (MTI)
Limitations of MTI Performance

Definitions:

- MTI Improvement Factor (I_c)
  - Defined earlier

$$I_C = \frac{(S/C)_{out}}{(S/C)_{in}}$$

- Subclutter Visibility(SCV)
  - The ratio by which a signal may be weaker than the coincident clutter and stll be d... the specified P_d and P_{fa}. All radial ... assumed equally likely.

$$SCV = (C/S)_{IN}$$

- Clutter Visibility Factor (V_{oc})
  - The Signal to Clutter ratio after filtering that provides the specified P_d and P_{fa}.

$$V_{OC} = (S/C)_{OUT}$$

Moving Target Indicator Radar (MTI)
Limitations of MTI Performance

Definitions:

- Clutter Attenuation

$$CA = (C_{IN} \;/\, C_{OUT})$$

  - Defined earlier

n

n

- Cancellation Ratio

  - The ratio by which a signal may be weaker than the coincident clutter and stll be n detected with the specified P_d and P_{fa}. All radial n velocities

- Notes

$$I_C = \left(\frac{C}{S}\right)_{IN} \bullet \left(\frac{S}{C}\right)_{OUT} = (SCV)(V_{OC})$$

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

<u>Equipment Instabilities:</u>

Changes in signal from pulse to pulse will result in apparent clutter Doppler shift

These changes can have many sources

- pulse to pulse change in amplitude
- pulse to pulse change in frequency
- pulse to pulse change in phase
- timing jitter
- Changes in pulse width
- Changes in oscillator frequency between Tx and Rx

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

<u>Equipment Instabilities:</u>

Changes in signal from pulse to pulse will result in apparent clutter Doppler shift

These changes can have many sources

n

- pulse to pulse change in amplitude
- pulse to pulse change in frequency

n

- pulse to pulse change in phase n
- timing jitter
- Changes in pulse width
- Changes in oscillator frequency between Tx and Rx

Moving Target Indicator Radar (MTI) Limitations of MTI

Equipment Instabilities: Performance

Example: Phase variation

g_1 and g_2 are succesive pulses

for a stationary target

$$g_1 = A\cos\omega t$$

$$g_2 = A\cos(\omega t + \Delta\phi)$$

n

The output of the two pulse filter is

$$g_1(t) - g_2(t) = 2A\sin\left(\frac{\Delta\phi}{2}\right)\sin\left(\omega t + \frac{\Delta\phi}{2}\right) \approx A\Delta\phi\sin\left(\omega t + \frac{\Delta\phi}{2}\right)$$

Resulting in a minimum Improvement Factor of

$$I = \frac{A^2}{(A\Delta\phi)^2} = \frac{1}{(\Delta\phi)^2}$$

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

Equipment Instabilities:

$$I = \frac{A^2}{(A\Delta\phi)^2} = \frac{1}{(\Delta\phi)^2}$$

n

Note that if we need I_C=40dB, n

The pulse to pulse phase variation has to be less than 0.01 rad (0.6º) n

n

Moving Target Indicator Radar (MTI) Limitations of MTI

Equipment Instabilities: Performance

Some examples of the effects of instability

Transmitter frequency	$(\pi \Delta f \tau.)^{-2}$	where	Δf = interpulse frequency change
Stalo or coho frequency	$(2\pi \Delta f T)^{-2}$		B = bandwidth
Transmitter phase shift	$(\Delta\phi)^{-2}$		τ = pulse width
Coho locking	$(\Delta\phi)^{-2}$		T = transmission time
Pulse timing	$\tau^2/(\Delta t)^2 2B\tau$		$\Delta\phi$ = interpulse phase change
Pulse width	$\tau^2/(\Delta\tau)^2 B\tau$		Δt = timing jitter
Pulse amplitude	$(A/\Delta A)^2$		$\Delta\tau$ = pulse width jitter
			ΔA = interpulse amplitude change

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

<u>Internal Fluctuation of Clutter:</u>

Many sources of clutter are capable of motion of one sort or another (translation, oscillation)

Examples:

- Trees: leaves/branches oscillate with magnitude/frequency depending on the wind speed
- Vegetation: similar to trees (possibly less than trees)
- Sea: translational motion with variation in phase and magnitude
- Rain: translational motion with oscillation due to turbulence (thunderstorms)
- Chaff: similar to rain with higher magnitude

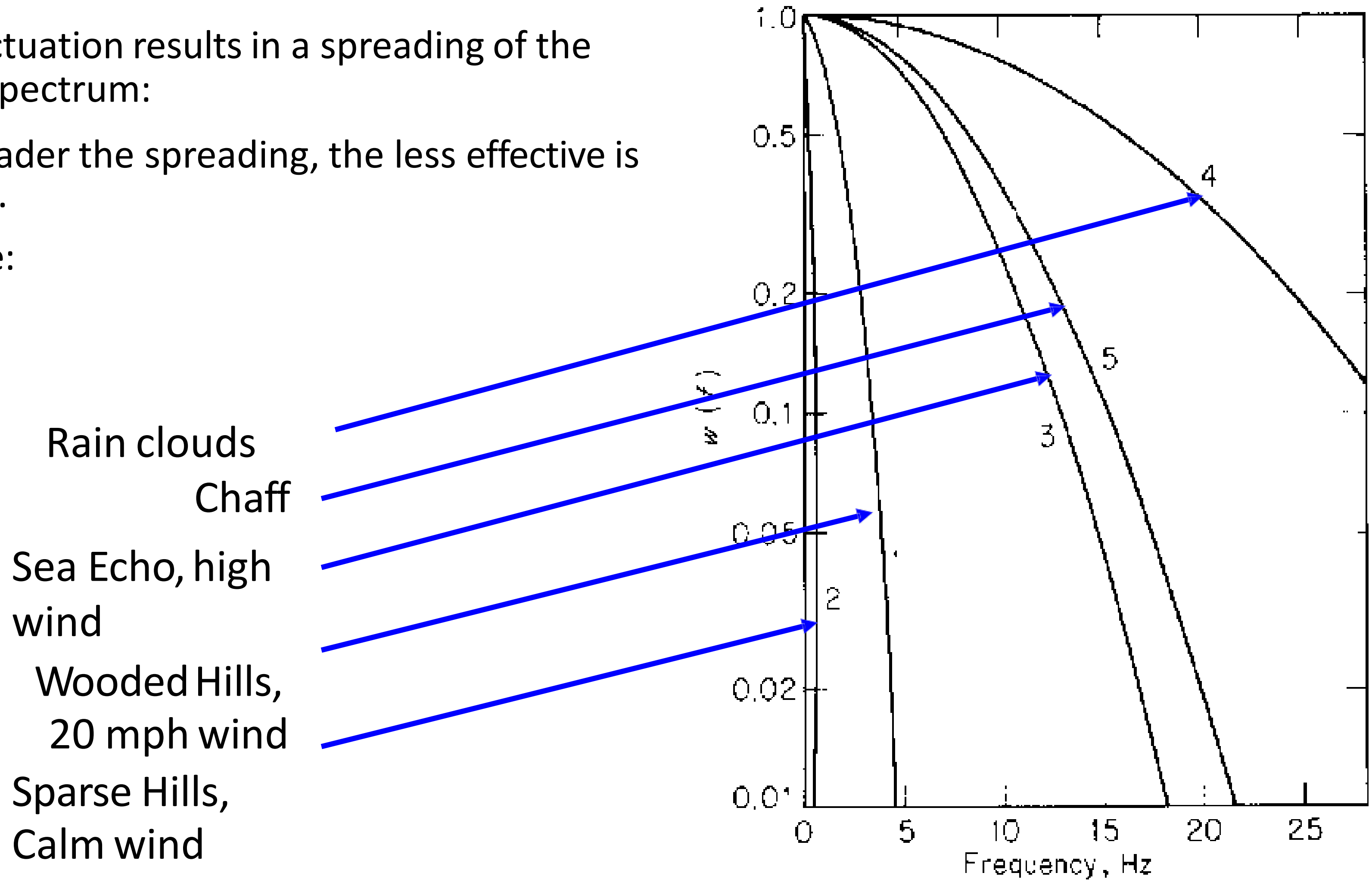
Moving Target Indicator Radar (MTI) Limitations of MTI Performance

Internal Fluctuation of Clutter:

This fluctuation results in a spreading of the clutter spectrum:

The broader the spreading, the less effective is the MTI.

Example:



Moving Target Indicator Radar (MTI) Limitations of MTI Performance

Internal Fluctuation of Clutter:

The spectrum of clutter can be expressed mathematically as a function of one of three variables:

1. a, a parameter given by Figure 4.29 for various clutter types
2. σ_C, the RMS clutter frequency spread in Hz
3. σ_v, the RMS clutter velocity spread in m/s

n

n

the clutter power spectrum is represented by W(f)

n

n

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

<u>Internal Fluctuation of Clutter:</u>

The power spectra expressed in the three parameters are:

1. $$W(f) = |g(f)|^2 = |g_0|^2 \exp\left[-a\left(\frac{f}{f_0}\right)^2\right]$$

n

2. $$W(f) = W_0 \exp\left[\frac{-f^2}{\boxed{2\sigma_c^2}}\right]$$

n

n

3. $$W(f) = W_0 \exp\left[\frac{-f^2\lambda^2}{\boxed{8\sigma_v^2}}\right]$$

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

Clutter Attenuation

The definition of Clutter Attenuation is:

$$CA = \frac{\int_0^\infty W(f)\,df}{\int_0^\infty W(f)\,|H(f)|^2\,df}$$

n

n

n

The frequency response of a single delay line filter is

n

$$2\sin(\pi f_d T)$$

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

Clutter Attenuation

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n

n

n

The frequency response of a single delay line filter is

n

$$2\sin(\pi f_d T)$$

and the spectrum of the clutter in terms of frequency is

$$\exp(-f^2/2\sigma_C^2)$$

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

Clutter Attenuation

Then

$$CA = \frac{\int_0^{\infty} W_0(f) \exp[-f^2/2\sigma_c^2]\, df}{\int_0^{\infty} W_0 \exp[-f^2/2\sigma_c^2]\, 4\sin(\pi f T)^2\, df}$$

Simplifying

n

$$CA = \frac{f_p^2}{4\pi^2 \sigma_c^{\ 2}}$$

n

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

<u>Clutter Attenuation</u>

Note that

$$\sigma_C = \frac{2\sigma_v}{\lambda} \qquad \text{and} \qquad a = \frac{c^2}{8\sigma_V^2}$$

Thus

$$CA = \frac{f_p^2 \lambda^2}{16\pi^2 \sigma_v^2}$$

and

$$CA = \frac{a f_p^2}{2\pi^2 f_0^2}$$

In terms of the parameter a

n n l n t n n e r m s o f v e l o

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

Improvement Factor

Since the average gain of a two pulse canceler is 2.

$$I_{1c} = \frac{f_p^2}{2\pi^2\sigma_c^2} = \frac{f_p^2\lambda^2}{8\pi^2\sigma_v^2} = \frac{a f_p^2}{\pi^2 f_0^2}$$

n

n

And for the three pulse canceler it is 6

$$I_{2c} = \frac{f_p^4}{8\pi^4\sigma_c^4} = \frac{f_p^4\lambda^4}{128\pi^4\sigma_v^4} = \frac{a^2 f_p^4}{2\pi^4 f_0^4}$$

In general

$$I_{NC} = \frac{2^{N_l}}{N_l!}\left(\frac{f_p}{2\pi\sigma_c}\right)^{2N_l}$$

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

Antenna Scanning Modulation

Since the antenna spends only a short time on the target, the spectrum of any target is spread even if the target is perfectly stationary:

The two way voltage antenna pattern is

$$G(\theta) = G_0 \exp\left[\frac{-2.776\theta^2}{\theta_B^2}\right]$$

n n

Dividing numerator and d ϵ n can rate

$$S_a = G_0 \exp\left[\frac{-2.776\left(\frac{\theta}{\dot{\theta}_s}\right)^2}{\left(\frac{\theta_B}{\dot{\theta}_s}\right)^2}\right]$$

Moving Target Indicator Radar (MTI) Limitations of MTI Performance

Antenna Scanning Modulation

Since

$$\frac{\theta}{\dot{\theta}_s} = t \quad \text{and} \quad \frac{\theta_B}{\dot{\theta}_s} = t_0 \quad \text{(time on target)}$$

n

n

$$S_a = K \exp\left[\frac{-2.776 t^2}{t_0^2}\right]$$

n

Taking the Fourier Transform

n

$$S_a = K_1 \exp\left[\frac{-\pi^2 f^2 t_0^2}{2.776}\right]$$

Moving Target Indicator Radar (MTI)
Limitations of MTI Performance

Antenna Scanning Modulation

Since this is a Gaussian function the exponent must be of the form

$$\frac{f^2}{2\sigma_f^2}$$

n

n

Thus $$\frac{-\pi^2 f^2 t_0^2}{2.776} = \frac{f^2}{2\sigma_f^2}$$ and $$\sigma_f = \frac{1.178}{\pi t_0}$$ (voltage spectrum)

n

n

or $$\sigma_s = \frac{\sigma_f}{\sqrt{2}}$$ (power spectrum)

or $$\sigma_s = \frac{1}{3.77 t_0}$$

Moving Target Indicator Radar (MTI)
Limitations of MTI Performance

Antenna Scanning Modulation

Substituting into the equations for I_C ,

$$I_{1s} = \frac{n_B^2}{1.388} \qquad I_{2s} = \frac{n_B^4}{3.853}$$

n

n

n

n

Tracking with Scanning Radars (Track While scan)

Automatic Detection and Tracking (ADT)

Pure tracking radars use pencil beam antennas to determine the azimuth, elevation and range of a single target

Digital processing allows a surveillance radar to track many targets and also permits prediction of the target positions in the future which assisnts in collision avoidance.

Functions performed by ADT are:

n

n

n

- Detection
- Track initiation
- Track Association
- Track update
- Track smoothing
- Track termination

Tracking with Scanning Radars (Track While scan)

Automatic Detection and Tracking (ADT)

Target Detection (Range)

As described before, the range is divided into range cells or "bins" whose dimensions are close to the resolution of the radar.

Each cell has a threshold and if a predetermined number of pulses exceed the threshold a target is declared present

n

Target Detection (Azimuth)

n

Resolution better than antenna beamwidth is obtained by seeking the central pulse in the n pulses and using the azimuth associated with that pulse.

n

Thus theoretically the resolution is

n

$$\frac{f_p}{360 \cdot 6 \cdot \omega}$$

Tracking with Scanning Radars (Track While scan)

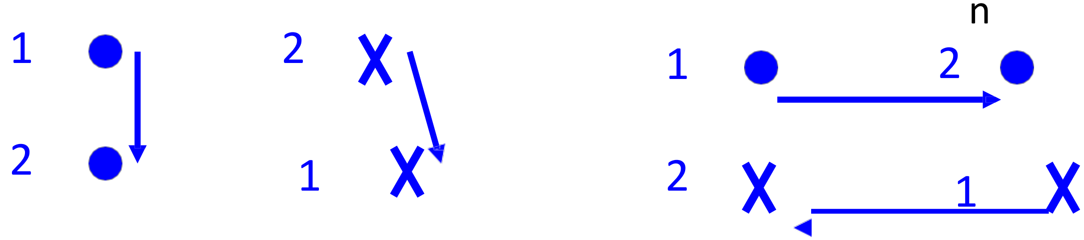
Automatic Detection and Tracking (ADT)

Track Initiation

Radar needs enough information to establish direction and speed of all targets present.

If only one target present, only two scans are required.

- Usually require many scans to build up all of the tracks present
- e.g. targets for two scans and two targets



Tracking with Scanning Radars (Track While scan)

Automatic Detection and Tracking (ADT)

Track Association

Radar attempts to associate each detection with an existing track

-establishes a search region (gate) for each establishend track,

- if detection falls inside gate, it is assumed to be assonciated with that track

n

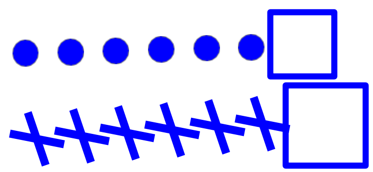
n

Tracking with Scanning Radars (Track While scan)

Automatic Detection and Tracking (ADT)

Track Association

Tradeoffs



Close tracks - small gate

n n

Small gate: can lose target if it manoeuvres

n

n

Gate size is made variable depending on

- Accuracy of track
- Expected acceleration of the target

Tracking with Scanning Radars (Track While scan)

Automatic Detection and Tracking (ADT)

Track Smoothing

Predictions are based on track history

<u>α-β Tracker</u>

predicted measured

n

n

$$\hat{x}_n = x_{pn} + \alpha(x_n - x_{pn})$$

n

$$\hat{v}_n = v_{n-1} + \frac{\beta}{T_S}(x_n - x_{pn})$$

n

Predicted position:

$$x_{pn+1} = \hat{x}_n + \hat{v}_n T_s$$

UNIT –IV

TRACKING RADAR

1. Introduction

- Tracking radar systems are used to measure the targets range, azimuth angle, elevation angle, and velocity

- Predict the future values

- Target tracking is important to military and civilian purposes as missile guidance and airport traffic control

Target tracking

Targets are divided to two types:

1 Single target

2 Multiple targets

Single target

1 Angle tracking

A- Sequential lobing B- Conical scan

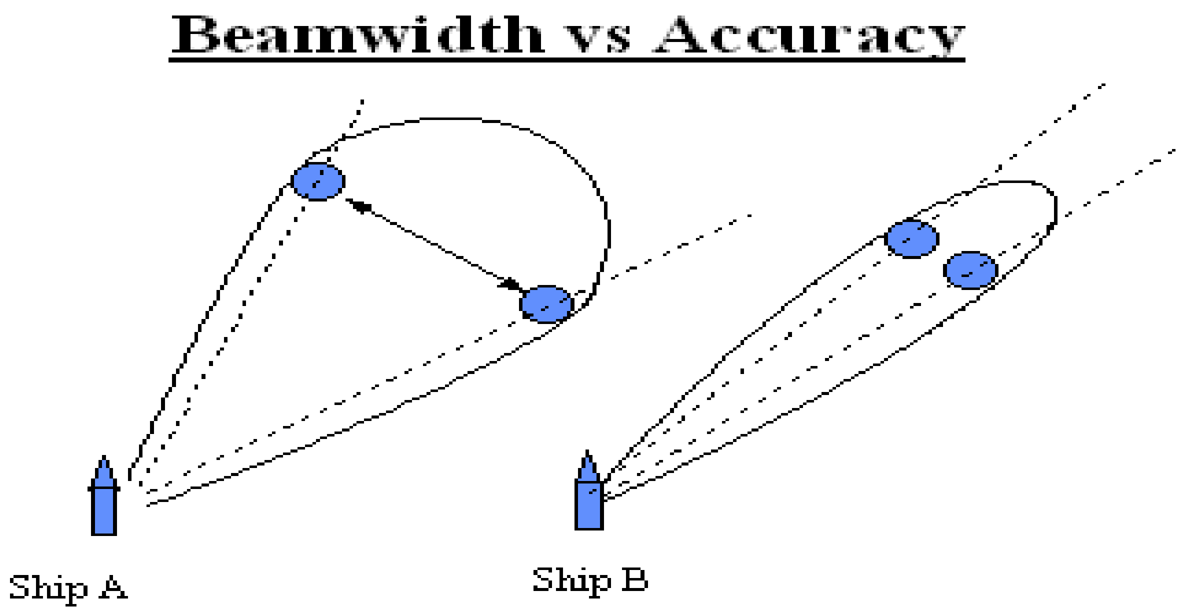
C- Amplitude compression monopulse

D- Phase compression monopulse

2 Range tracking

Relation between beamwidth and accuracy

Antennas with wide beamwidth are less accuracy than antennas with narrow beam

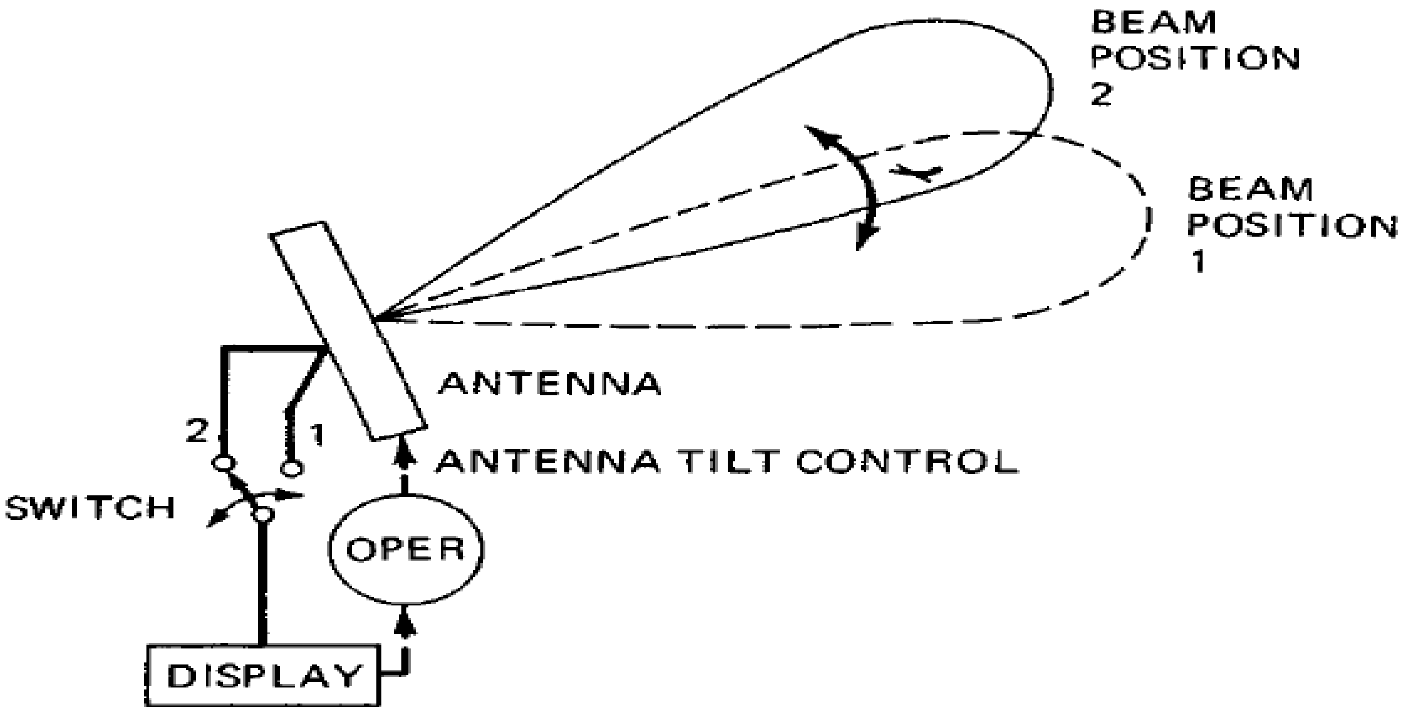


Pencil beam

In tracking processes radar used narrower beams

Line of Sight (LOS) axis

The LOS is called the radar tracking axis too



Error signal

- Describes how much the target has deviated from the beam main axis

- Radar trying to produce a zero error signal

- Azimuth and elevation error

1. Sequential lobing

- Sequential lobing is often referred to as lobe switching or sequential switching
- Accuracy depends on the pencil beam width
- It is very simple to implement

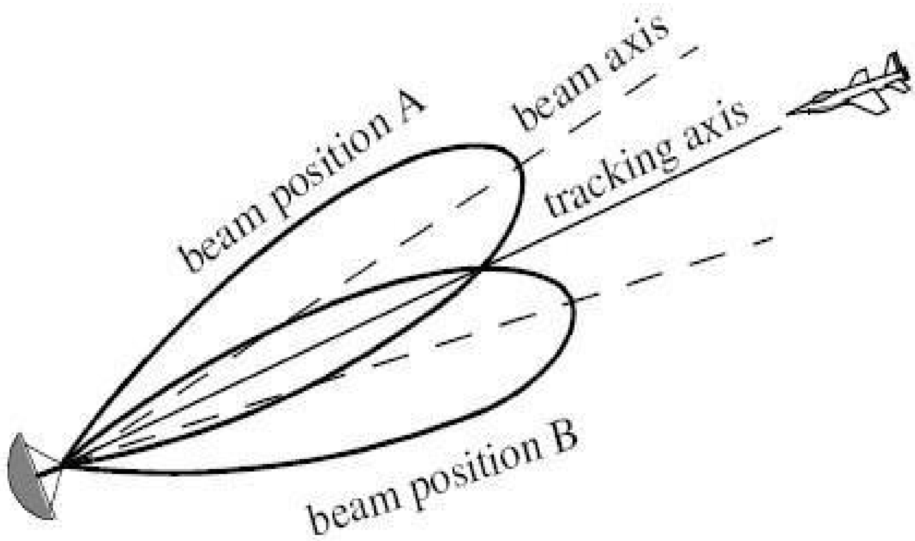
SCR- 268

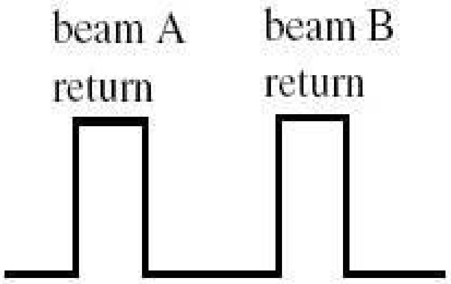
Concept of operation:

- Measuring the difference between the echo signals voltage levels

1- When the target being on the LOS

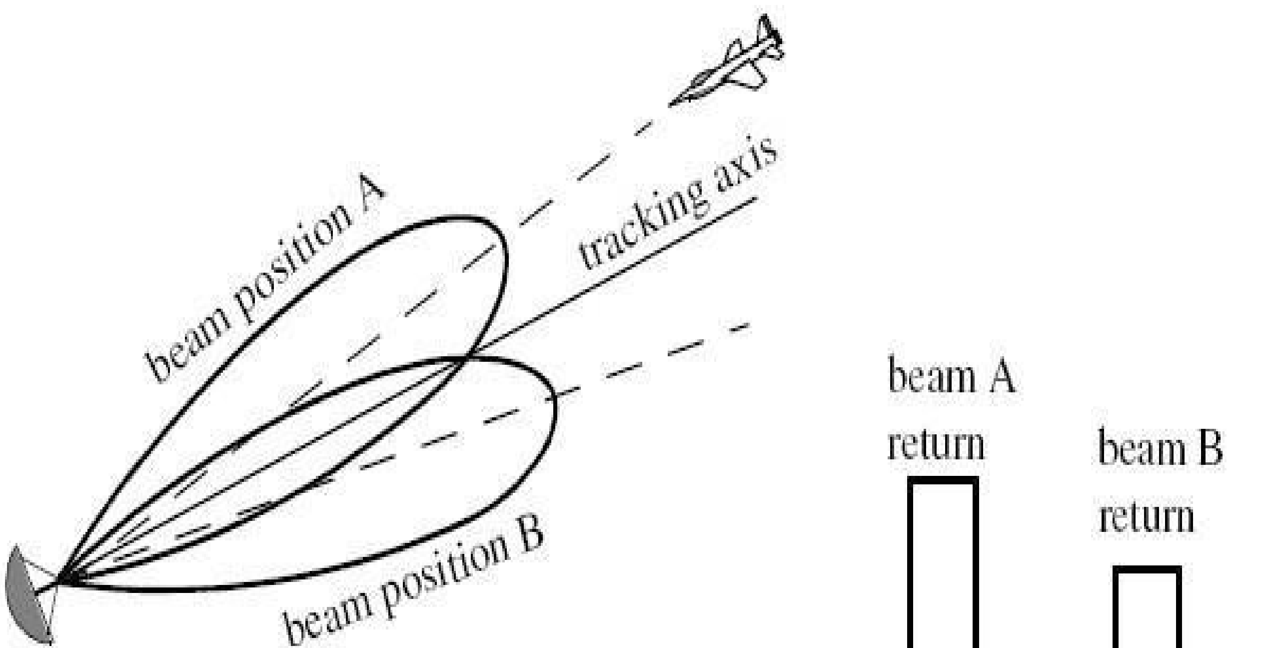
The difference between the echo signals voltage in (A) and (B) equal zero, that’s mean zero error signal



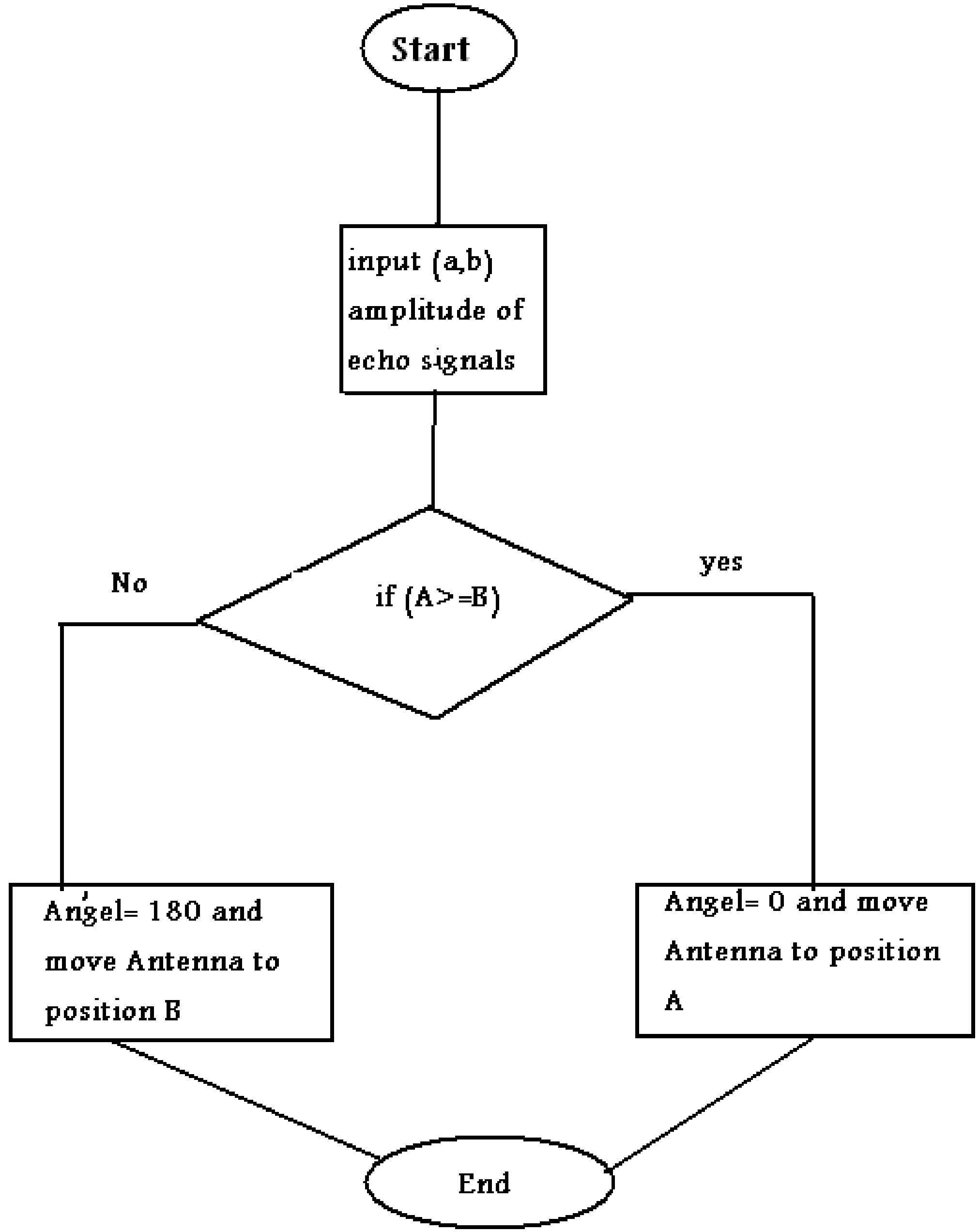


2. When the target being off the LOS

Signal in position(A) will attenuate more than signal in position(B) , that's mean a nonzero error signal



Mat lab Code

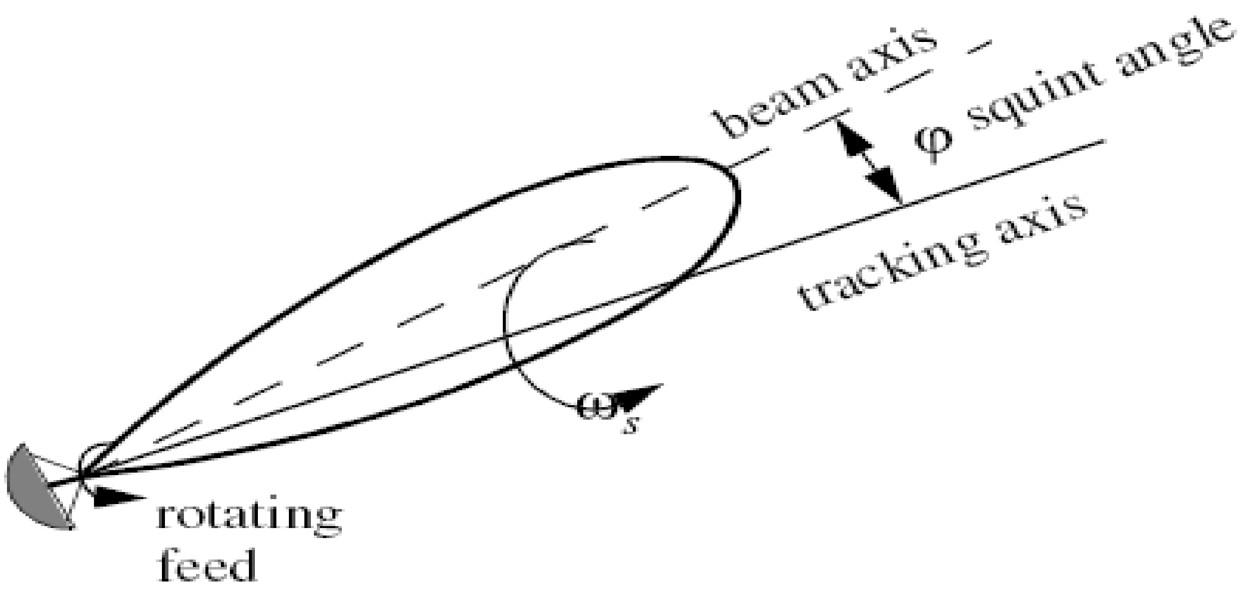


Start
input (a,b) amplitude of echo signals
No
if (A>=B)
yes
Angel= 180 and move Antenna to position B
Angel= 0 and move Antenna to position A
End

2. Conical scan

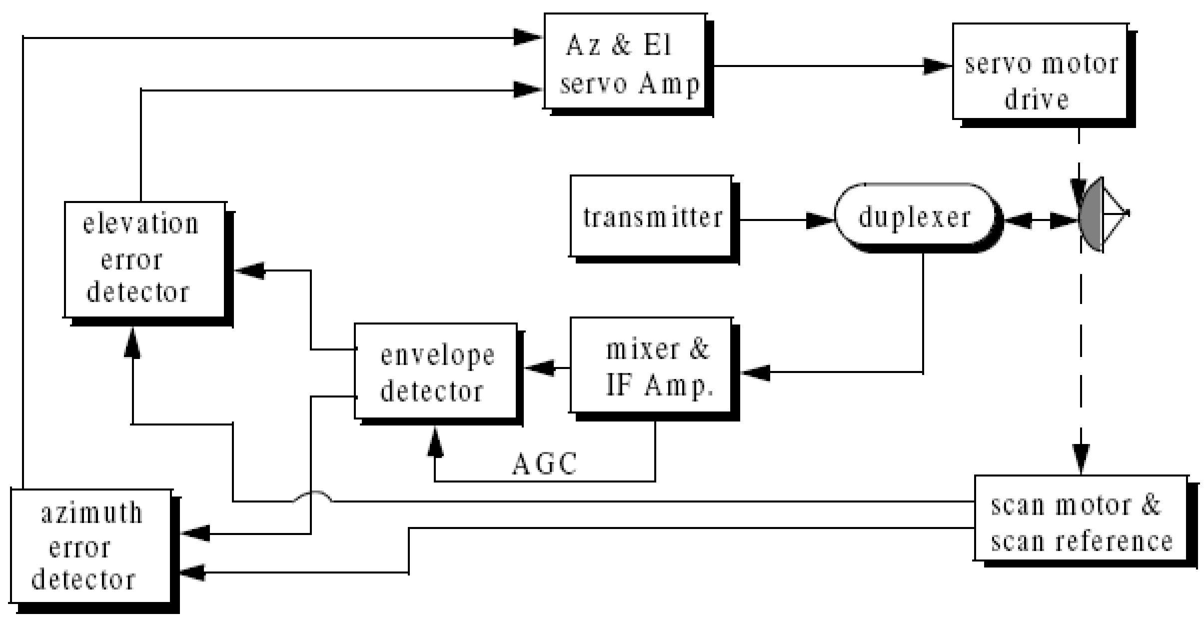
-It's an extension of sequential lobbing

-The feed of antenna is rotating around the antenna axis

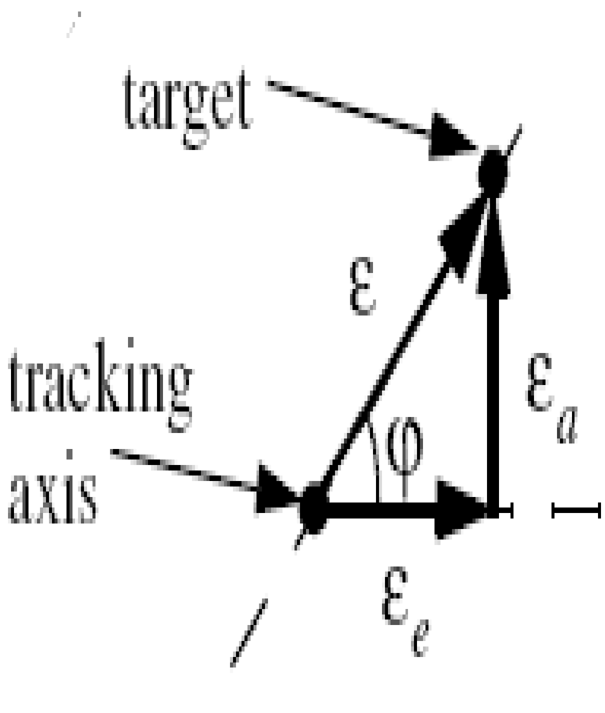


- The envelope detector is used to extract the return signal amplitude

- AGC is used to reduce the echo signal amplitude if it is strong and raises it when it is weaker



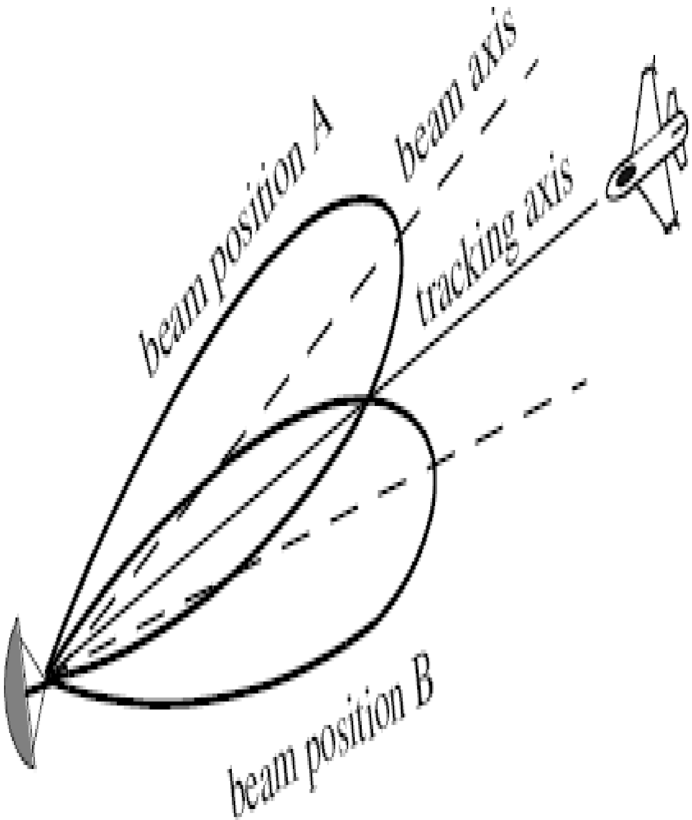
Elevation and azimuth error

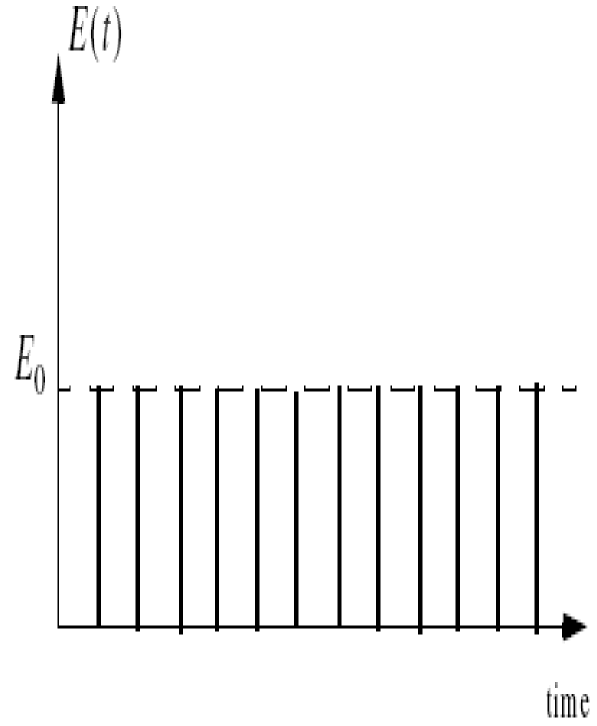


$$E_e(t) = -\frac{1}{2}E_0\cos\varphi$$

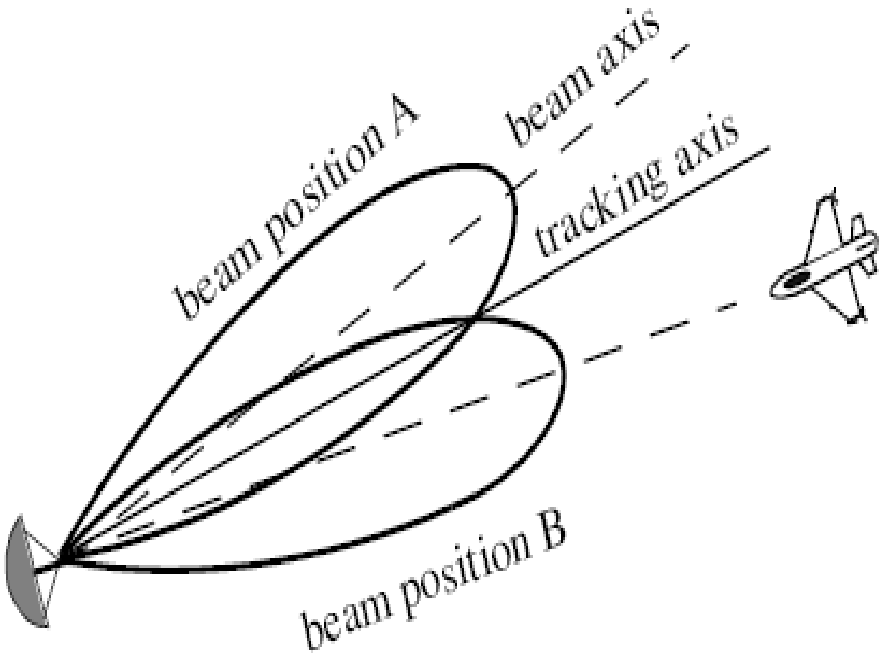
$$E_a(t) = \frac{1}{2}E_0\sin\varphi$$

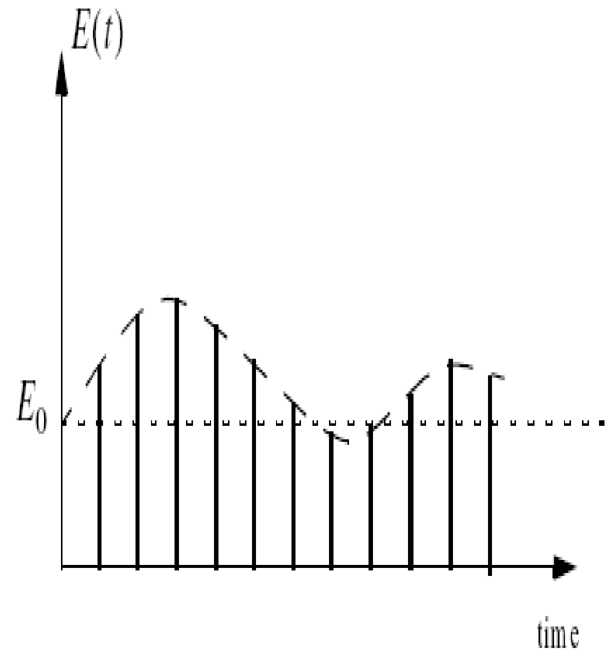
1- When the target being on the LOS





2. When the target being off the LOS



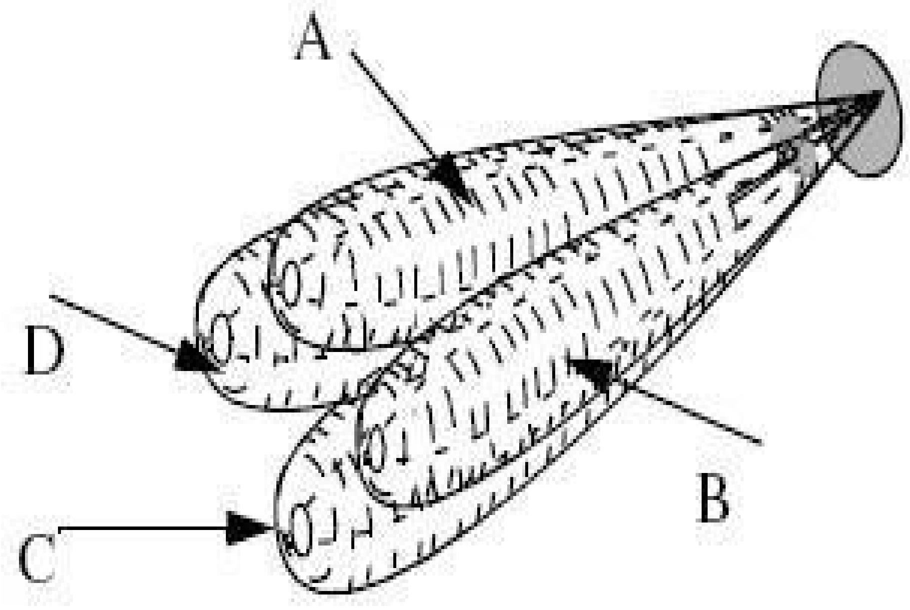


3. Amplitude compression monopulse

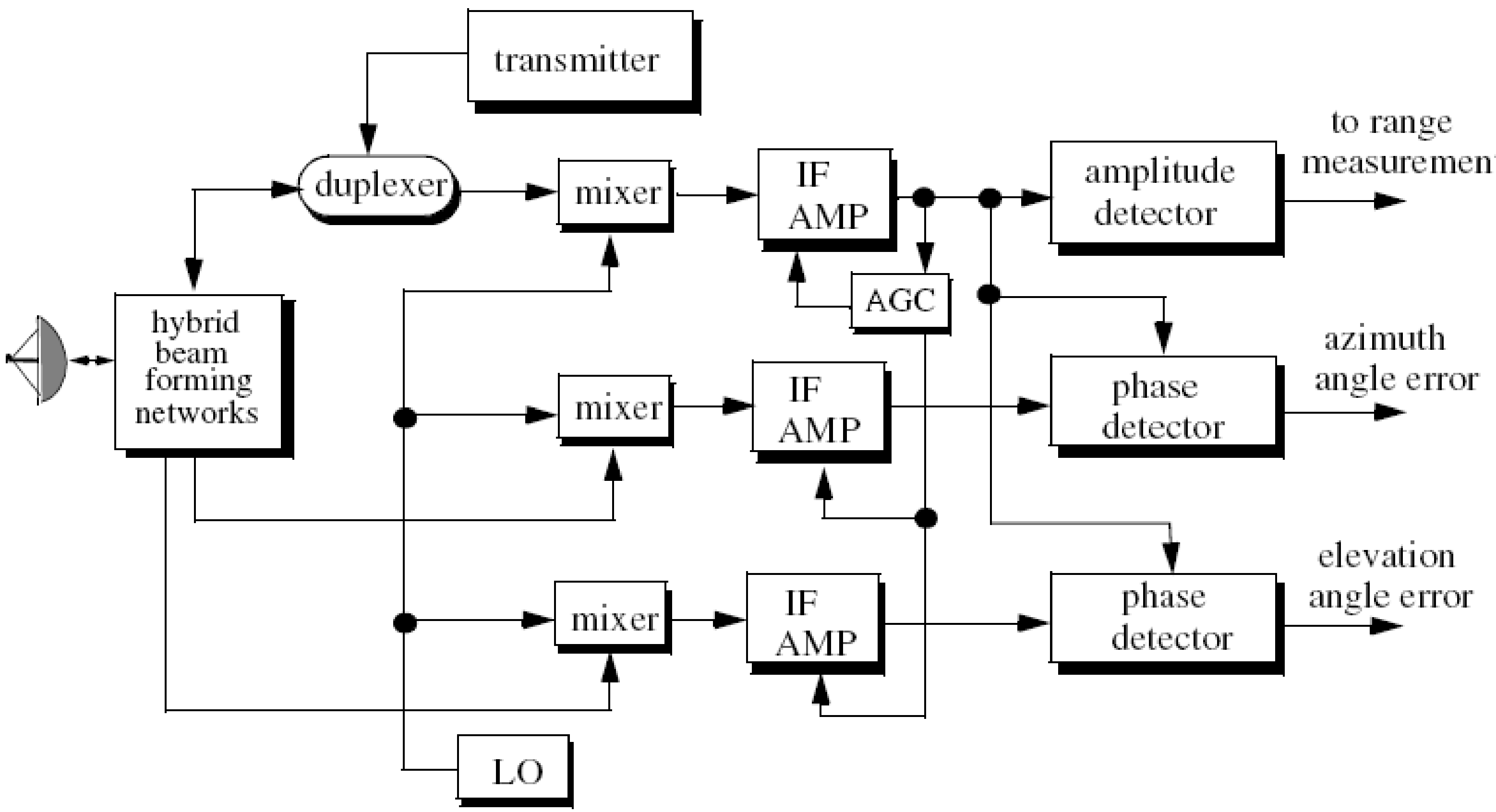
- This type is more accurate than sequential and conical scanning
- Feed generated four beams simultaneously with single pulse
- The four beams are inphase but have different amplitudes.

Four beams shape

Four feeds mainly horns are used to produce the monopulse antenna pattern

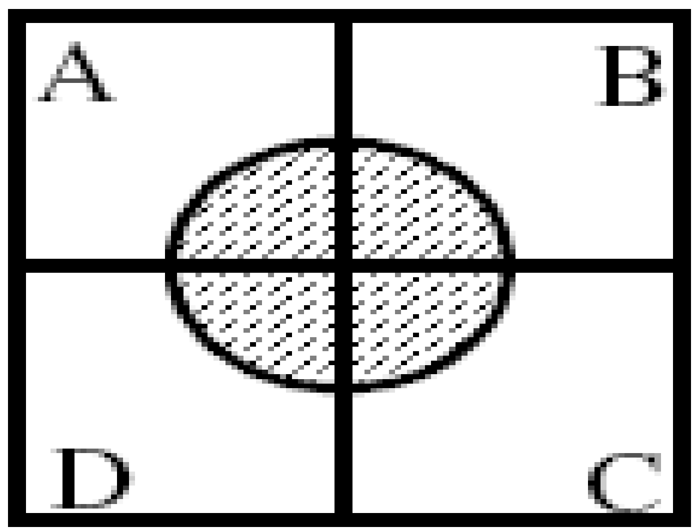


Simplified amplitude comparison monopulse radar block diagram

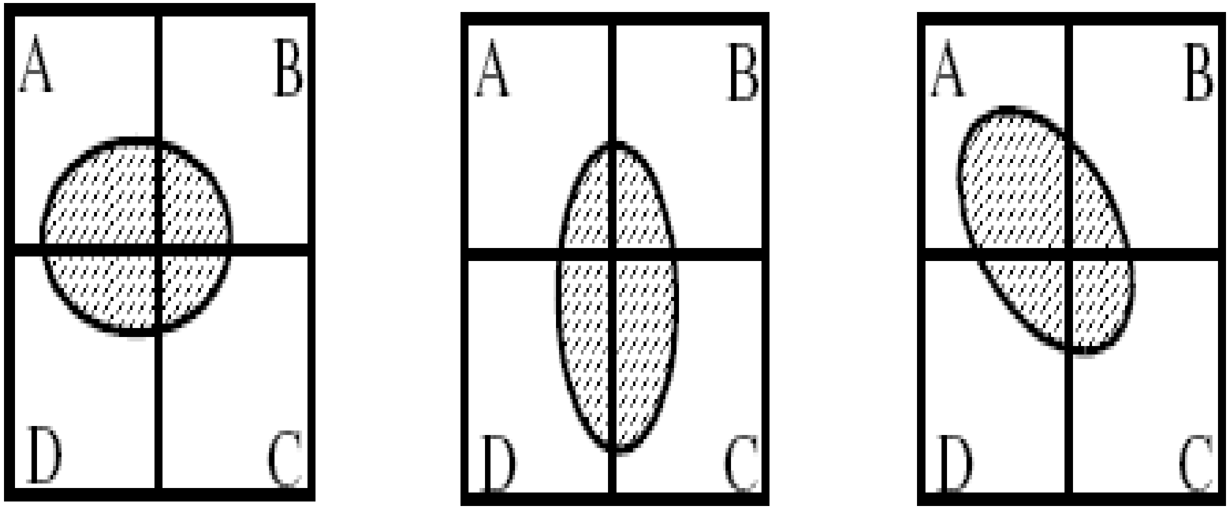


When the target being on the LOS

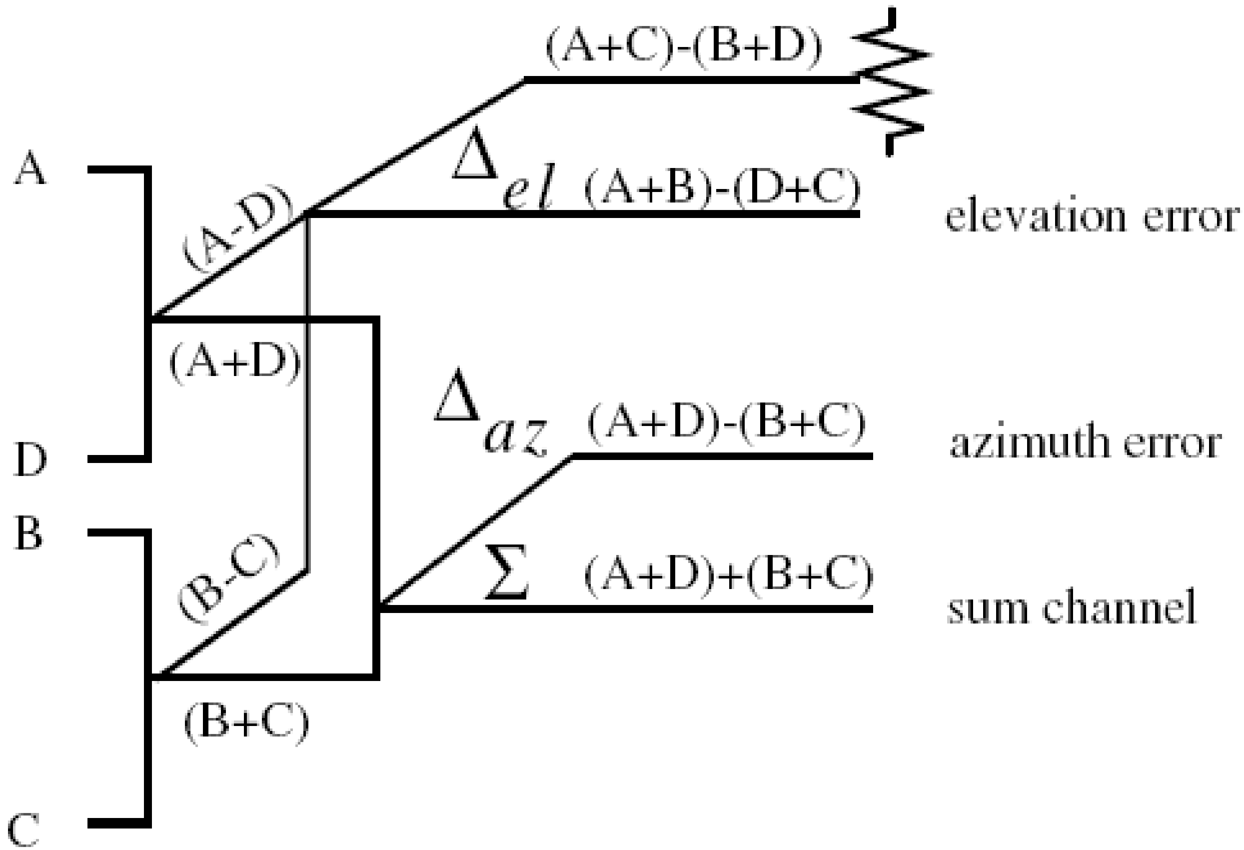
radar compares the amplitudes and phases of all echo signals of target



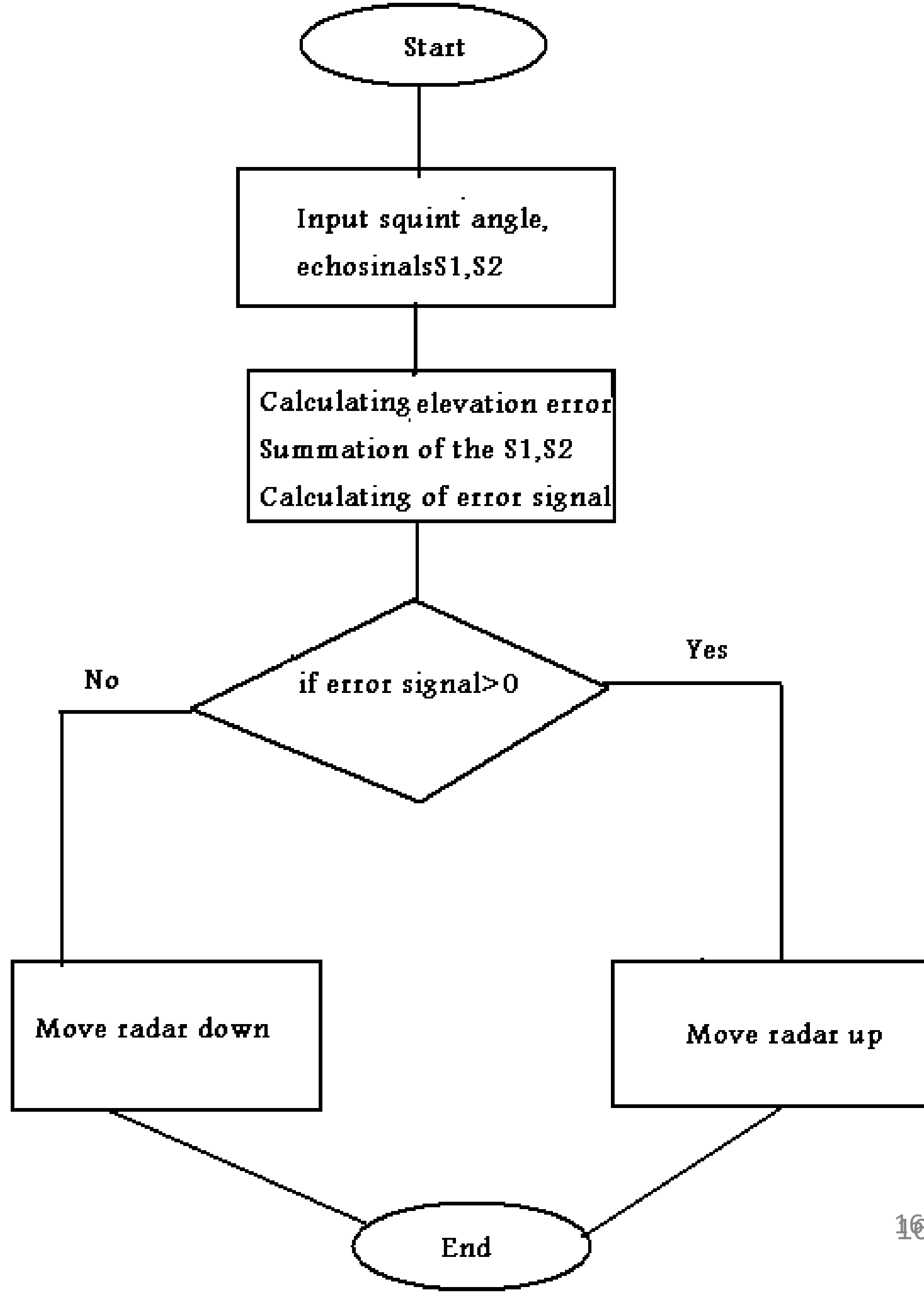
When the target being off the LOS



Microwave comparator circuitry

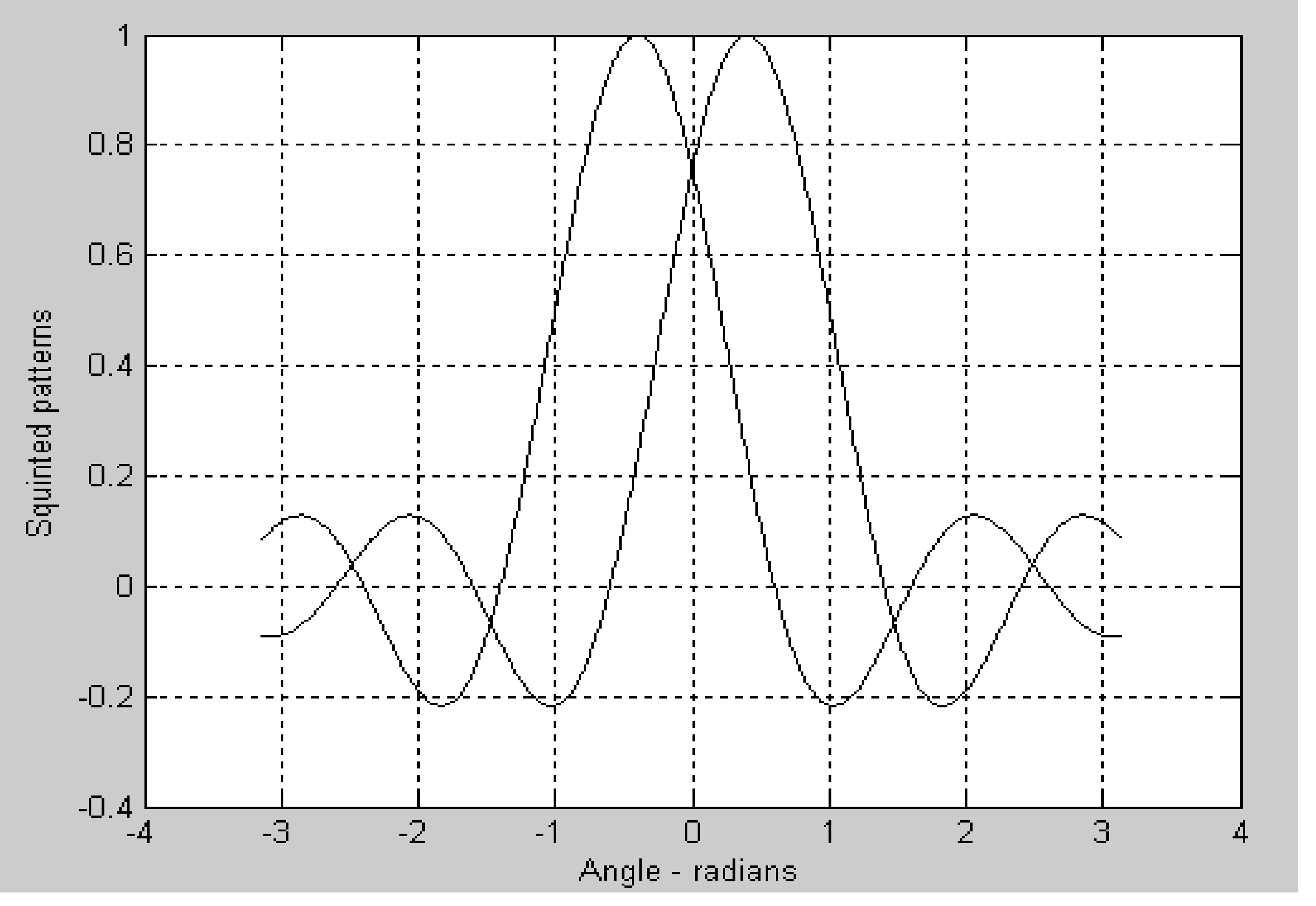


Mat lab code

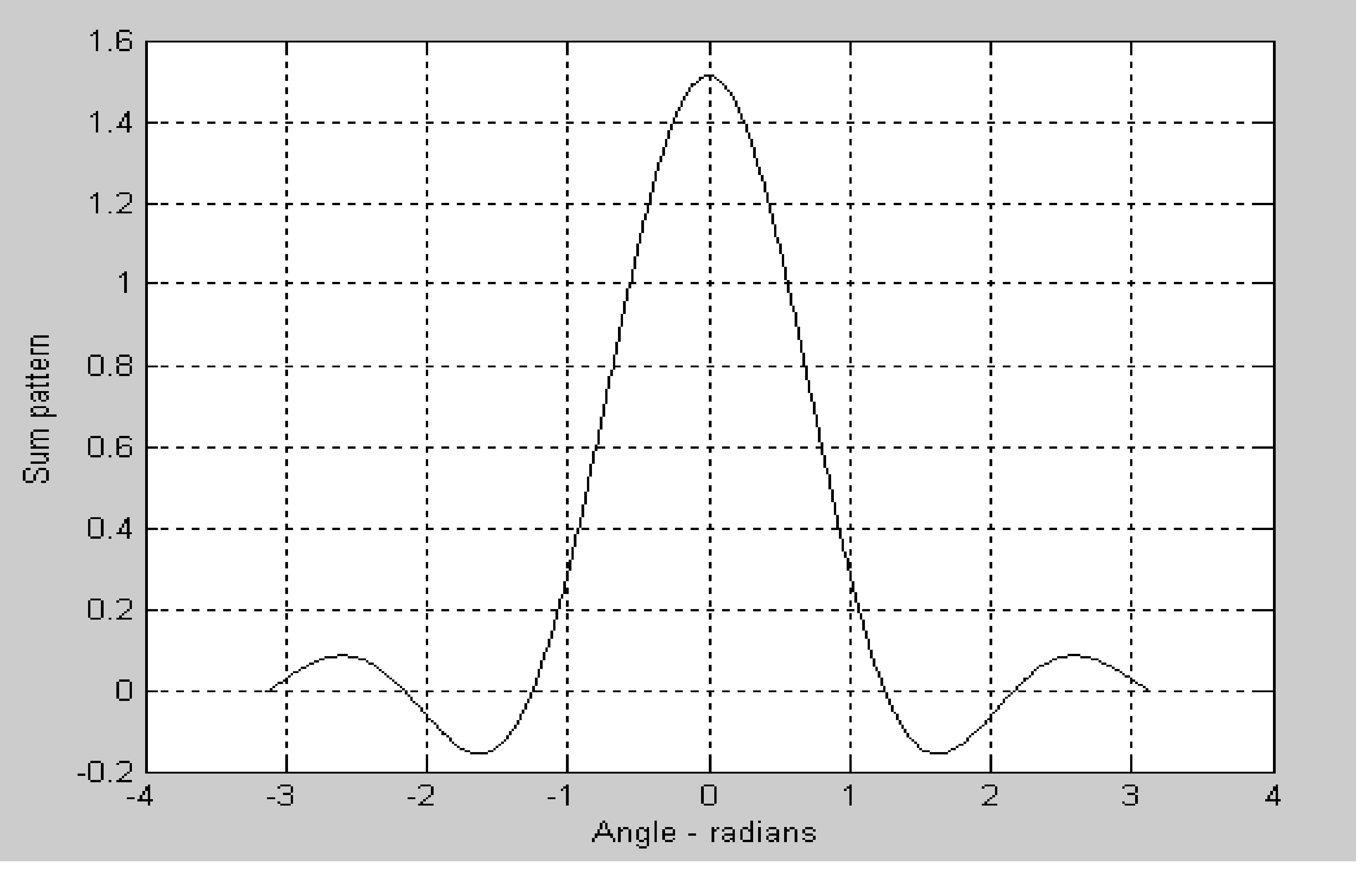


Start
Input squint angle,
echosinalsS1,S2
Calculating elevation error
Summation of the S1,S2
Calculating of error signal
if error signal>0
No
Yes
Move radar down
Move radar up
End

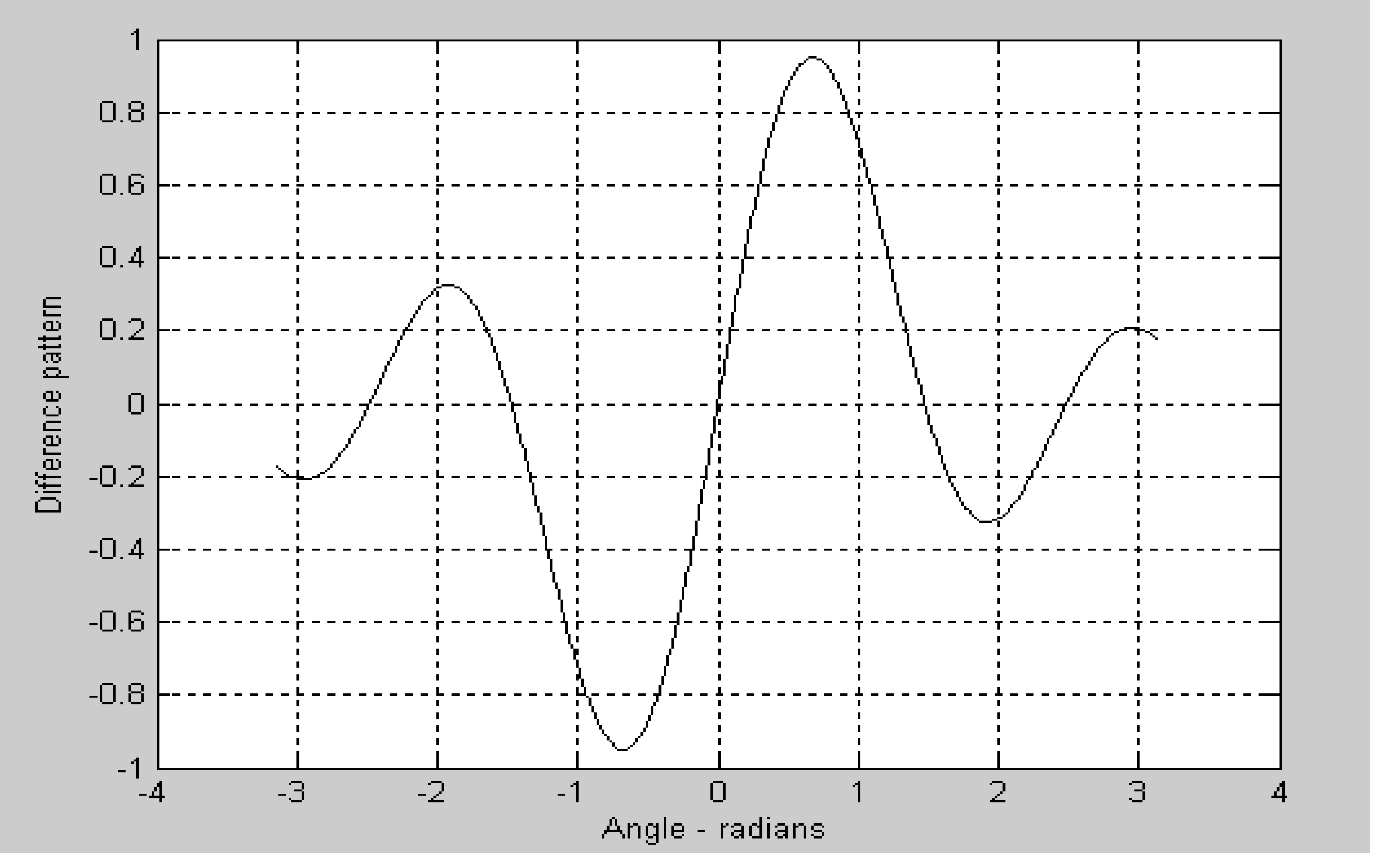
Two echo signals at squint angle (phi=0.4 rad)



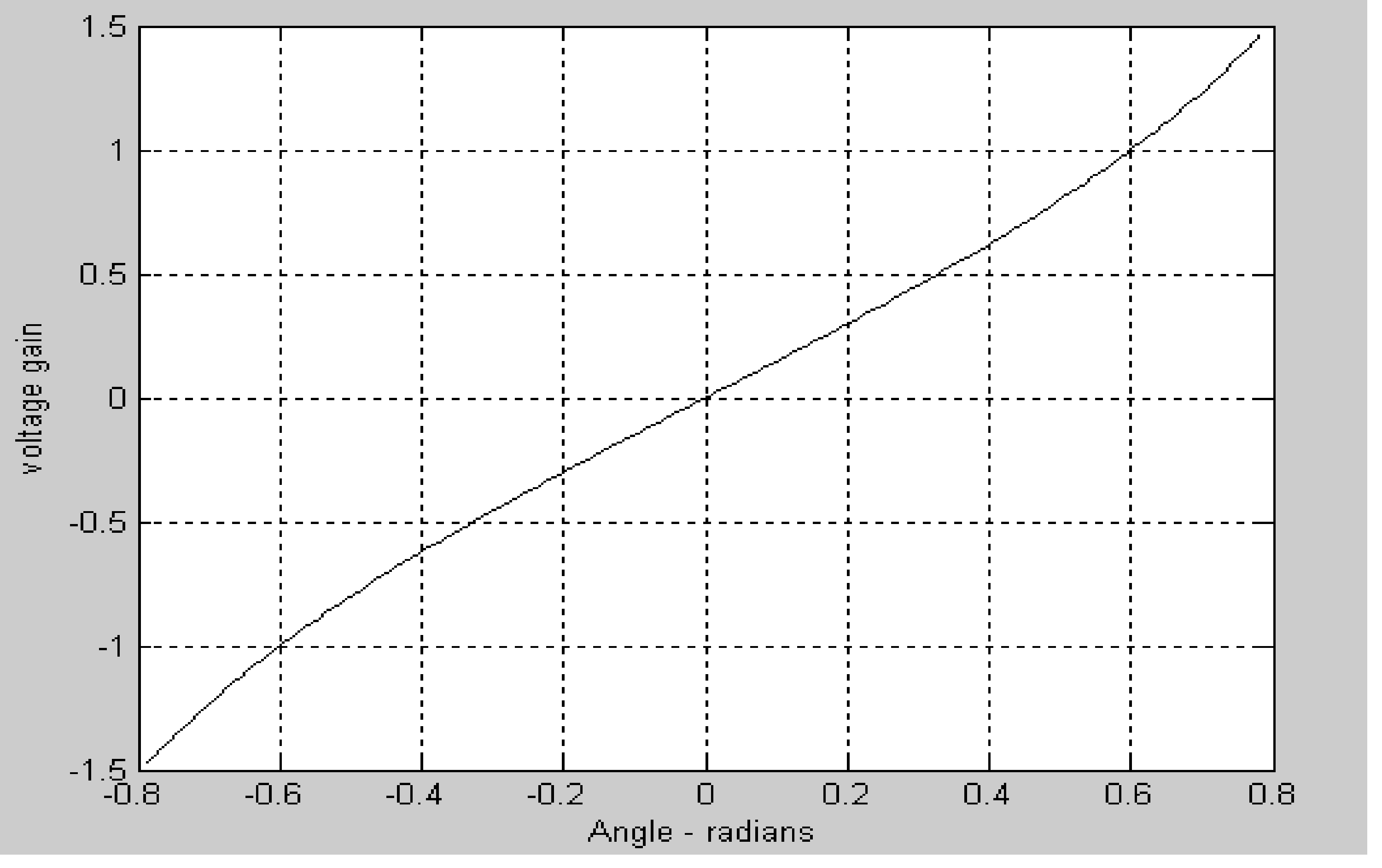
Sum of the two signals S1,S2



Difference between S1,S2



Elevation Error signal

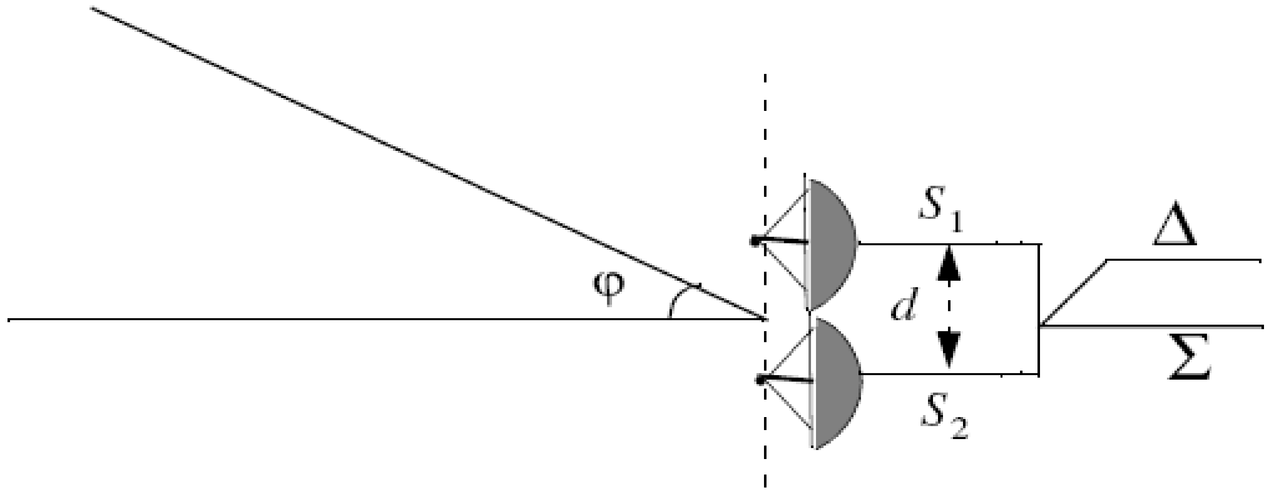


4- Phased compression monopulse

- It's the same as the last type but the amplitude here is equal for the four beams with different phases

•Phase comparison monopulse tracking radars use a minimum of a two-element array antenna

Single coordinate phase monopulse antenna



$$\frac{|\Delta|}{|\Sigma|} = \tan\left(\frac{\phi}{2}\right)$$

Range tracking

- Target range is measured by estimating the round-trip delay

$$R = \frac{c\,T_R}{2}$$

$$\text{where} \quad c = 3x10^{8},\ m/s$$

$$T_R = round-trip\,time,\ \text{sec}$$

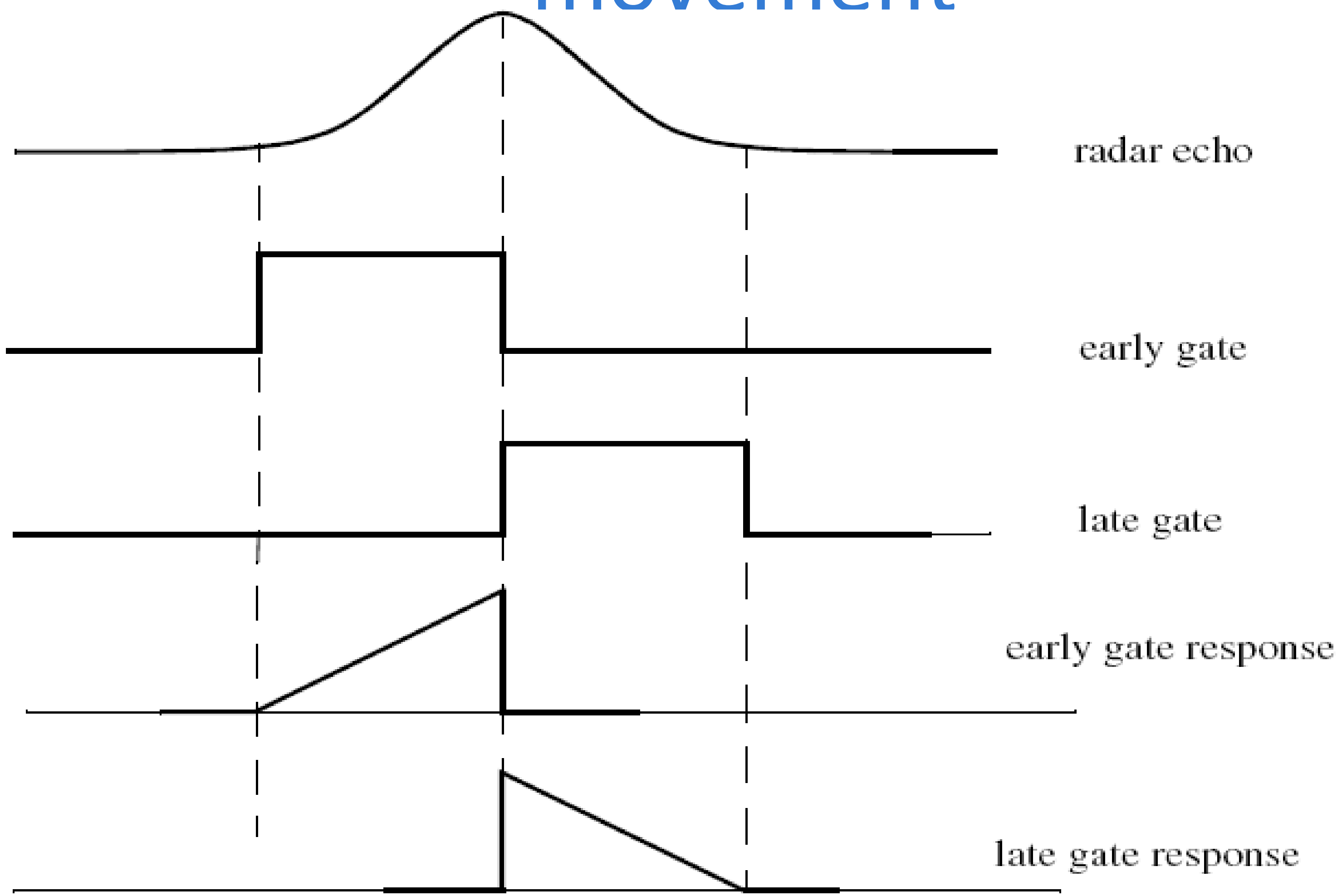
Split Gate System

- It consist of two gates:

1-Early gate 2- Late gate

- The early gate produces positive voltage output but the late gate produces negative voltage output.
- Subtracting & integration
- Output is: zero, negative or positive

Split range gate
- Its predict the target movement



Multiple Targets

Here the system is more difficult since:

- Tracking
- Scanning
- reporting

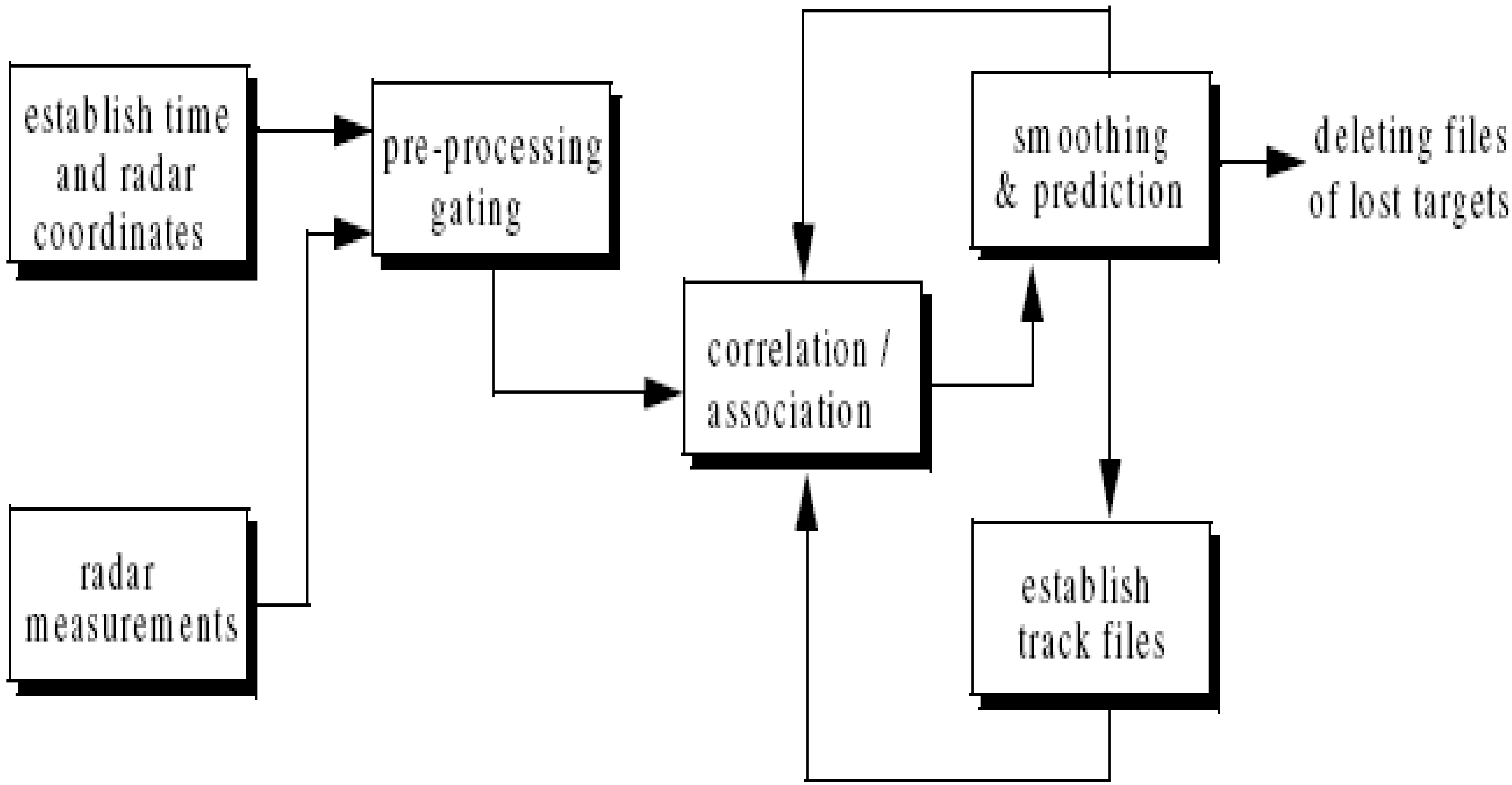
Track while scanning (TWS)

- This type of radar is used for multiple targets

- It scans for new targets while its tracking old targets

- When TWS scan a new target it initiates a new track file

Correlation unit is correlate old tracked file with a new scanned measurements



Any Two Radar Make

- Target detection
- Generation of tracking “Gates”
- Target track initiation and track file generation (if a new target)
- Correlation
- Track gate prediction, smoothing and positioning
- Display and future target calculations

Target Detection

This task is accomplished by two method :

- Circuit in receiver
- signal-processing equipment

Generation Gate

- Gate : small volume of space consist of many of cells

- Function : monitoring of each scan of the target information

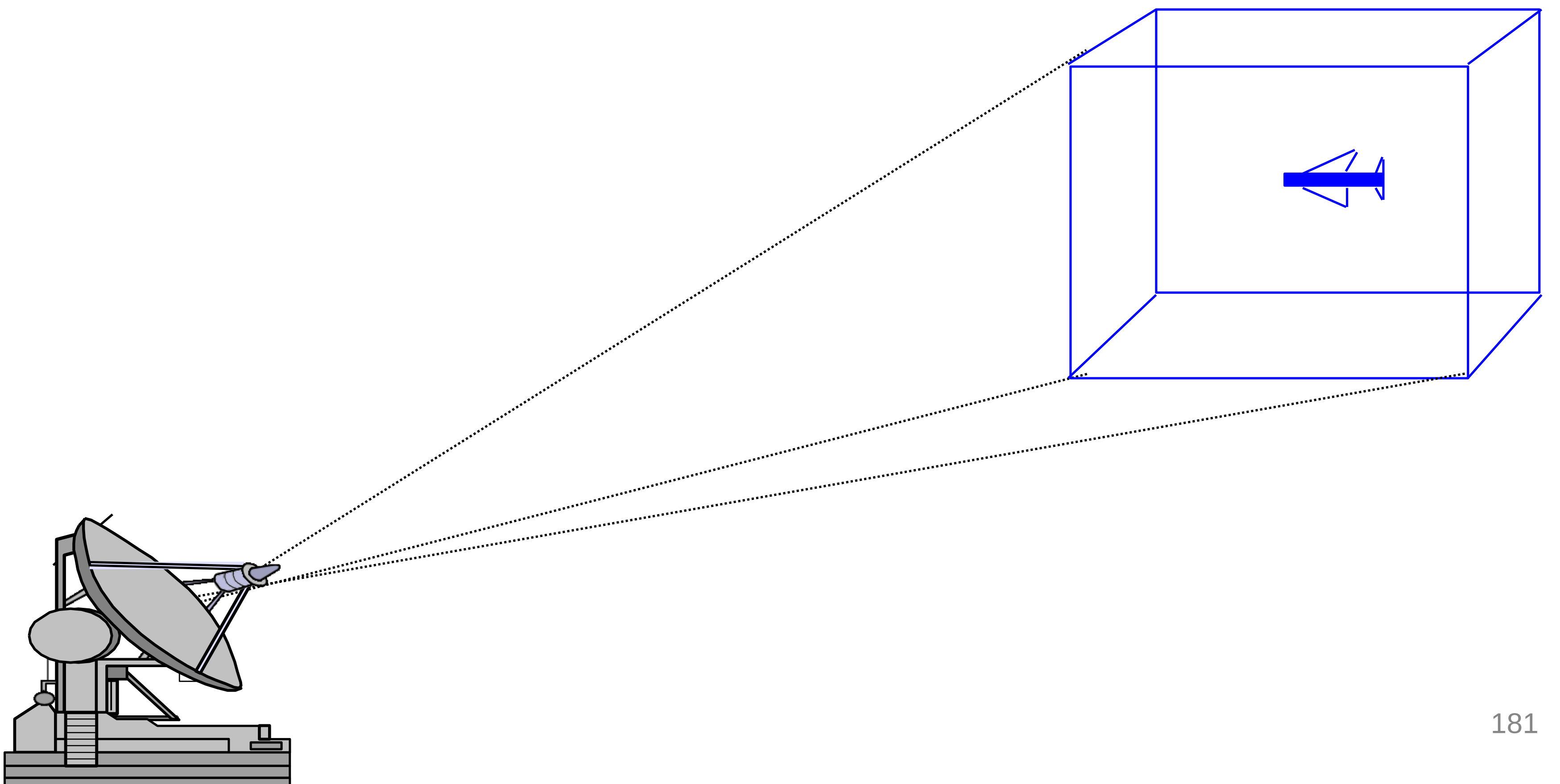
•Gating has responsibility for knowing if new/exist target

Gate Types

- Acquisition gate
- Tracking gate
- Turning gate

Acquisition Gate

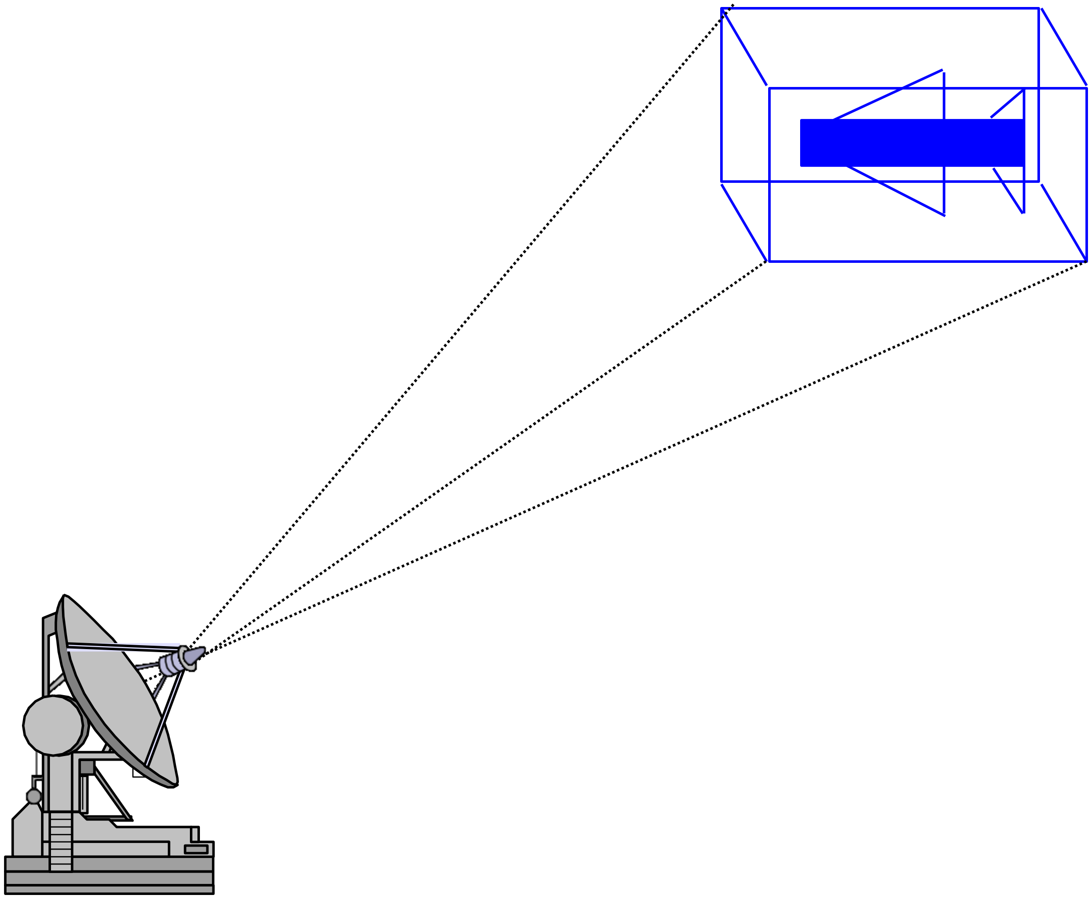
- This gate is large to facilitate target motion cross one scan period



Tracking Gate

- This gate is generated when the target is within the acquisition gate on the next scan
- It is very small gate
- It is moving to the new expected target position

Tracking Gate



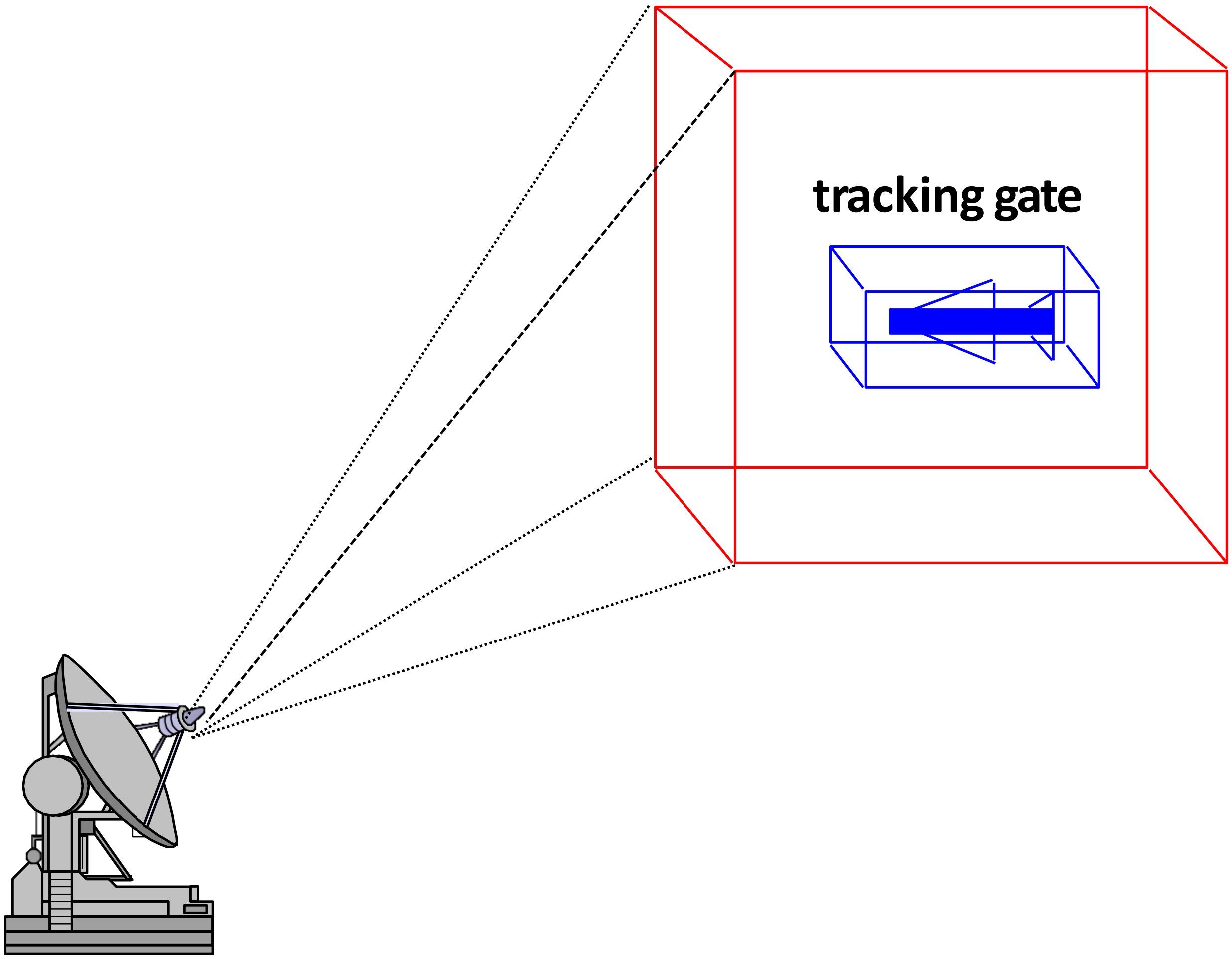
Turning gate

- It is generated if the observation within the tracking gate doesn’t appear

- It has larger size than tracking gate

- Tracking gate included by it

Turning gate



Target track correlation and association

- All observations site on the boundary of tracking gate must be correlate with that track

- Each observation is compared with all track files

- Perhaps, observation is correlated with one track files ,several tracks or no tracks

Tracking Ambiguity Results

- If the observation correlates with more one track files, tracking ambiguity is appear.

- Two reasons cause this result:

1 several targets site in the same gate

2 several gates overlap on a single target

How To Solve Ambiguity?

- If the system designed so that an operator initiate the tracks, then solution by delete track

- But for the automatic systems , the solving by maintain software rules

Target track initiation and track file generation

- The track file is initiated when acquisition gate is generated

- Track file store position and gate data

- Each track file occupies position in the digital computer's high-speed memory

- Cont. refreshed data

Track gate prediction, smoothing and positioning

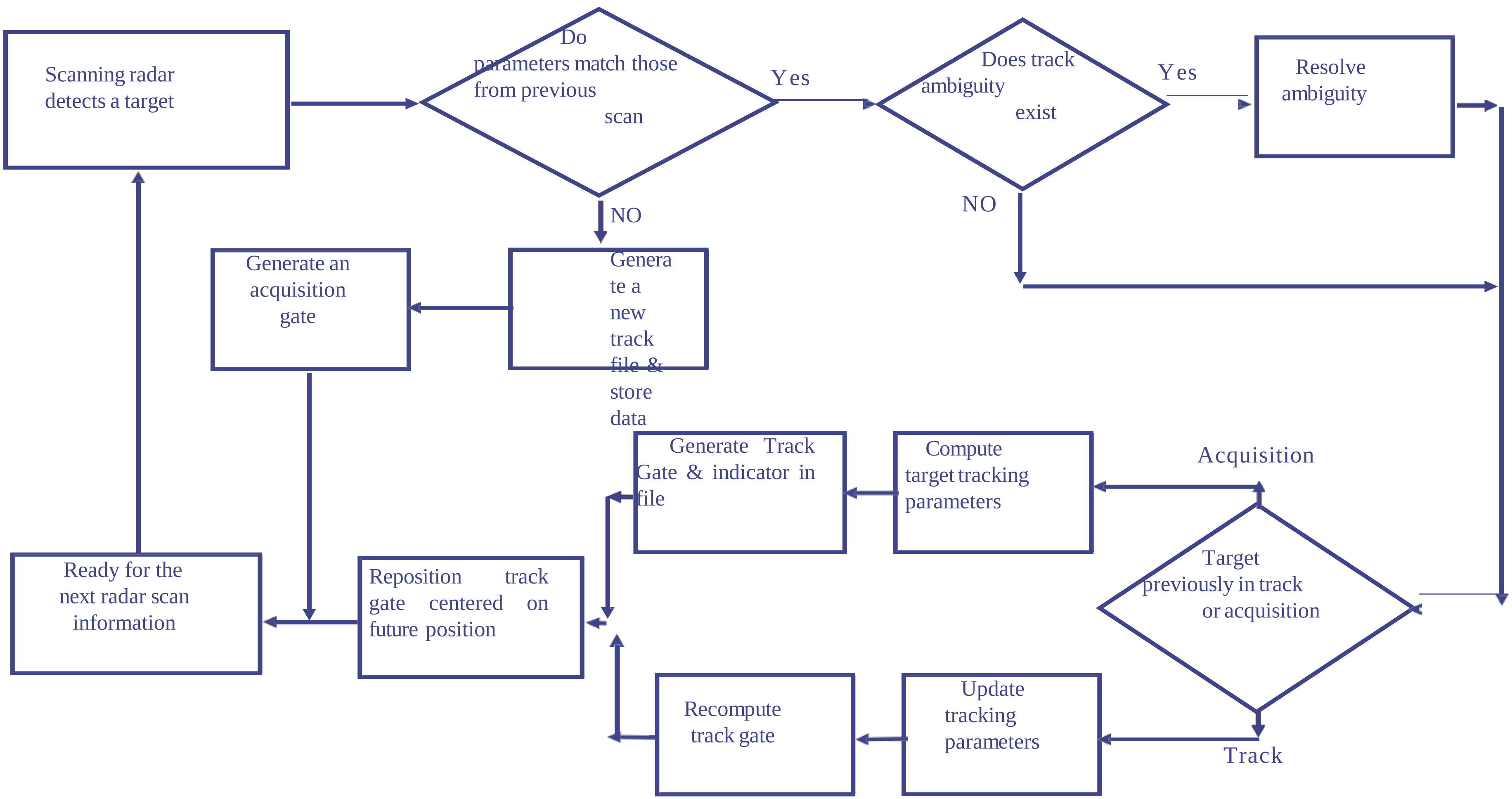
-Error → Repositioning → Smoothing

-The system lagged the target

-The system leading the target

-smoothing is completed by comparing predicted parameters with observed parameters

TWS System Operation



Conclusion

- We discussed the concepts of the different ways to determine the angle of a target and its range
- We show the different between single and multiple targets tracking
- We try to apply that on Matlab .

UNIT-V

Matched-Filter Receiver:

A network whose frequency-response function maximizes the output peak-signal- to-mean-noise (power) ratio is called a matched filter. This criterion, or its equivalent, is used for the design of almost all radar receivers

$$H(f) = G_a S^*(f) \exp(-j2\pi f t_1)$$

where $S(f) = \int_{-\infty}^{\infty} s(t) \exp(-j2\pi f t)\, dt$ = voltage spectrum (Fourier transform) of input signal

$S^*(f)$ = complex conjugate of $S(f)$

t_1 = fixed value of time at which signal is observed to be maximum

G_a = constant equal to maximum filter gain (generally taken to be unity)

$$|H(f)| \exp[-j\phi_m(f)] = |S(f)| \exp\{j[\phi_s(f) - 2\pi f t_1]\}$$

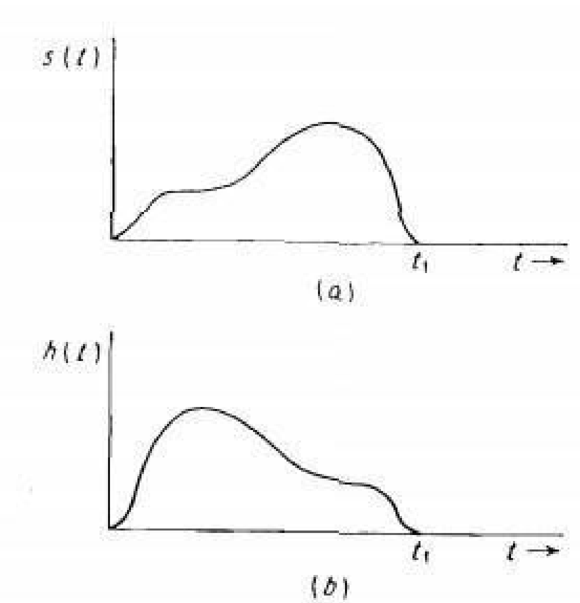
or $$|H(f)| = |S(f)|$$

and $$\phi_m(f) = -\phi_s(f) + 2\pi f t_1$$

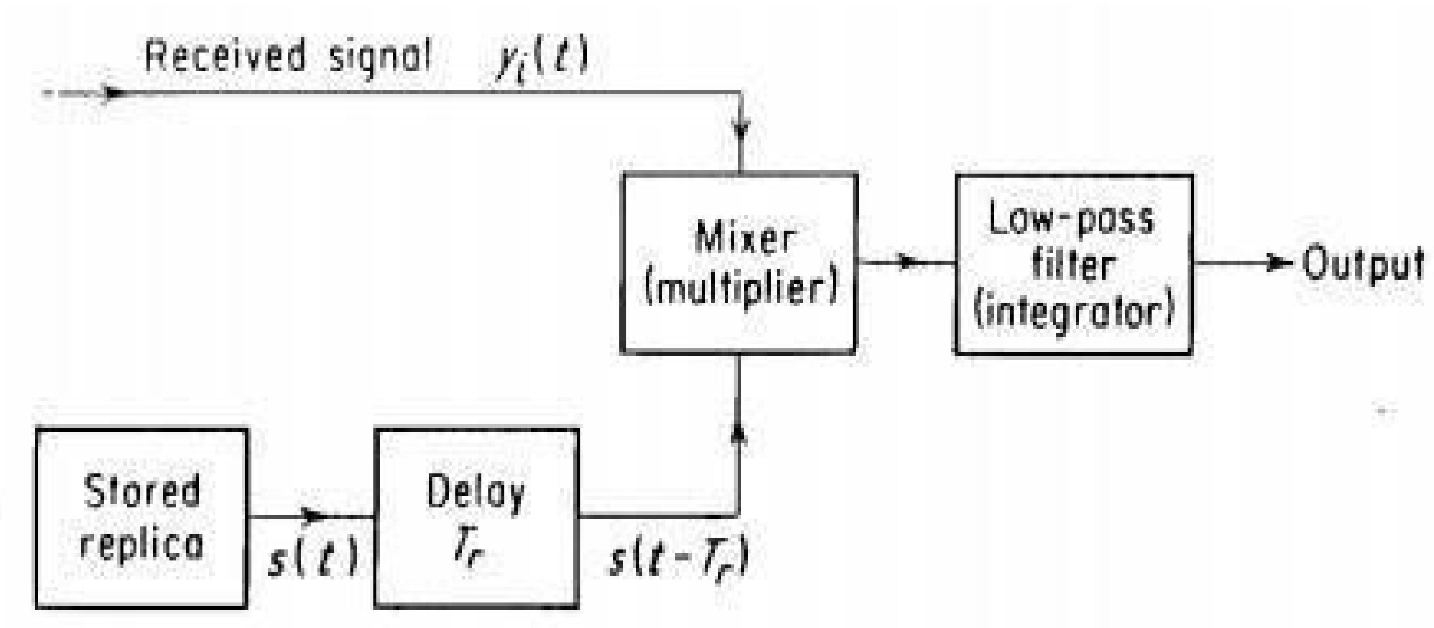
Derivation of the matched-filtercharacteristic:

$$H(f) = G_a S^*(f) \exp(-j2\pi f t_1)$$

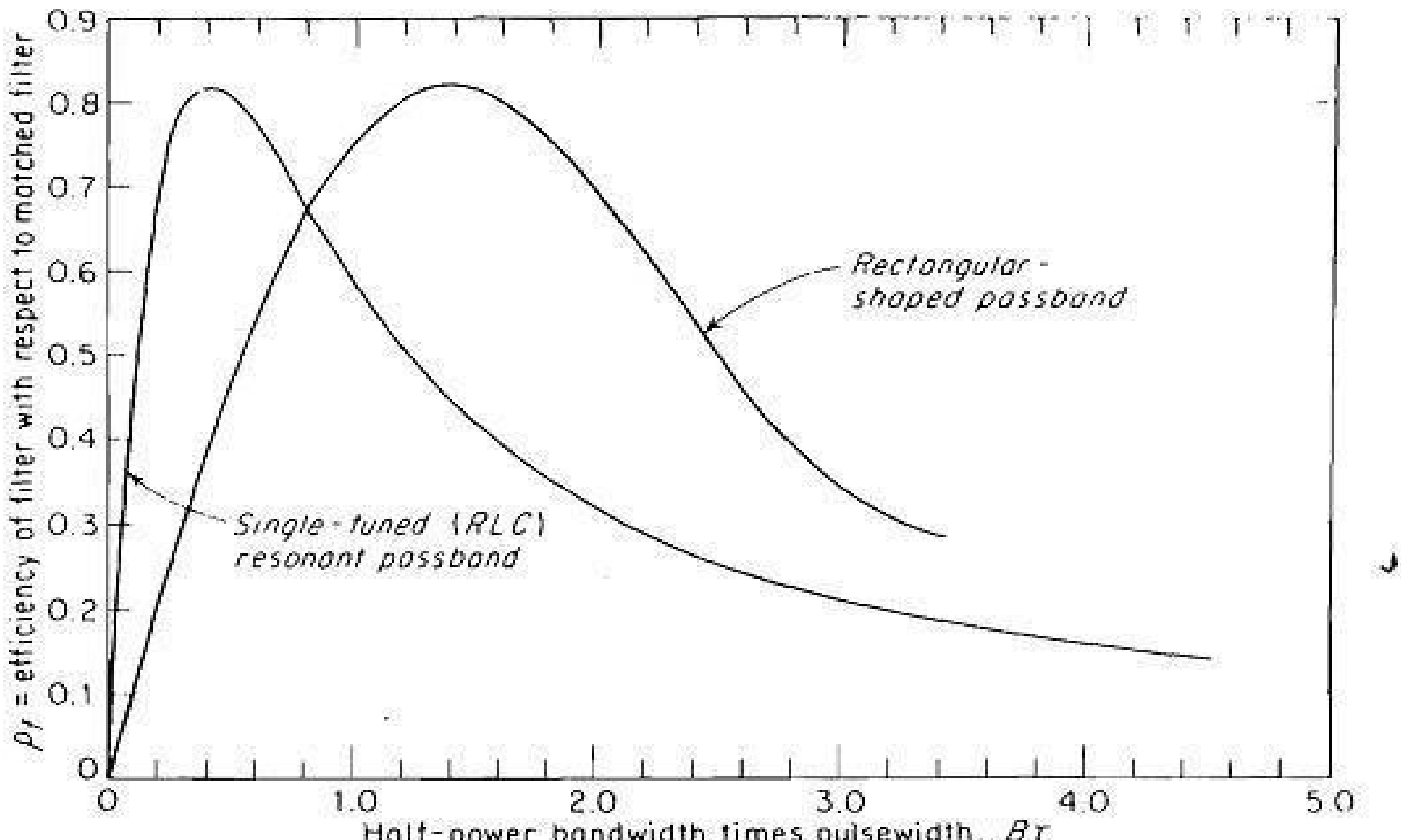
$$R_f = \frac{|s_o(t)|^2_{max}}{N}$$



Correlation function and cross correlation receiver



EFFICIENCY OF NON-MATCHED FILTERS



Input signal	Filter	Optimum $B\tau$	Loss in SNR compared with matched filter, dB
Rectangular pulse	Rectangular	1.37	0.85
Rectangular pulse	Gaussian	0.72	0.49
Gaussian pulse	Rectangular	0.72	0.49
Gaussian pulse	Gaussian	0.44	0 (matched)
Rectangular pulse	One-stage, single-tuned circuit	0.4	0.88
Rectangular pulse	2 cascaded single-tuned stages	0.613	0.56
Rectangular pulse	5 cascaded single-tuned stages	0.672	0.5

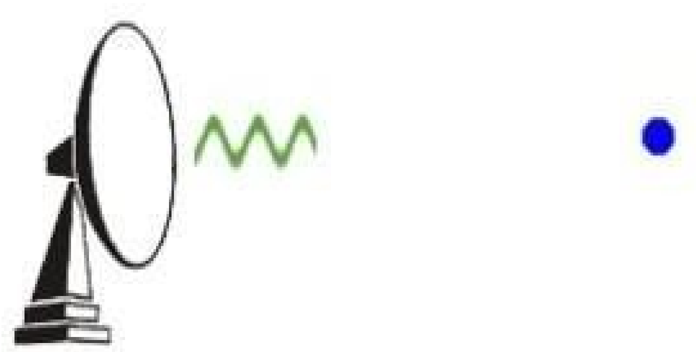
Matched filter withnonwhitenoise:

$$H(f) = \frac{G_a S^*(f) \exp(-j2\pi f t_1)}{[N_i(f)]^2}$$

$$H(f) = \frac{1}{N_i(f)} \times G_a \left(\frac{S(f)}{N_i(f)} \right)^* \exp(-j2\pi f t_1)$$

This indicates that the NWN matched filter can be considered as the cascade of two filters. The first filter, with frequency-response function l/Ni (f), acts to make the noise spectrum uniform, or white. It is sometimes called the whitening filter. The second is the matched filter when the input is white noise and a signal whose spectrum is S(f)/Ni(f).

Radar Receiver



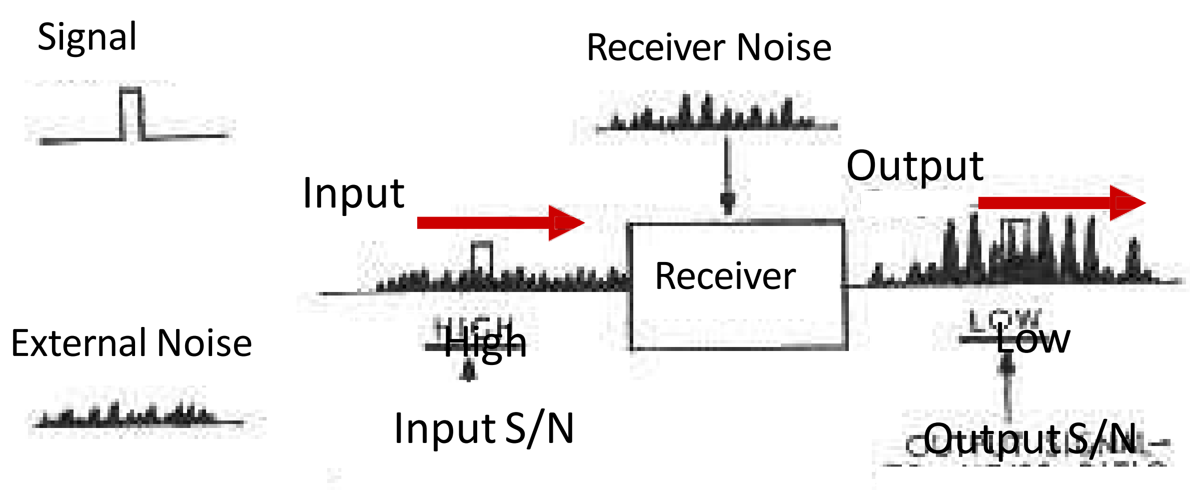
Pulse radars transmit a burst of energy and listen for echoes between transmissions.

Leakage from the transmitter
Very strong echoes from close-range clutter

Not occur at the receiving time

The received signal is usually heavily corrupted by:

- Environmental noise
- Interference
- Noise from the radar system itself



Receiver Components

Antenna: Some radar antennas include low-noise amplifiers prior **to forming the receive beams**

Duplexer

Permits a single antenna to be shared between transmitter and receiver.

RF Filters

The receiver filters the signal to separate desired echoes from interference

Low Noise Amplifiers

Amplify the weak echo with minimum added noise

Mixer

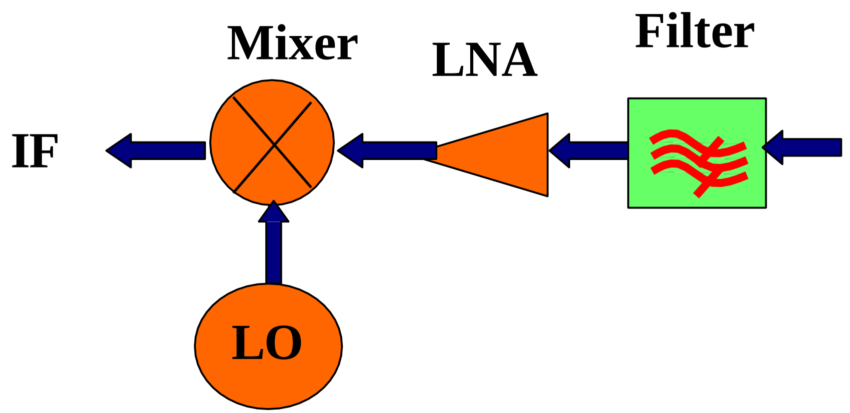
Down conversion

Oscillator

Protection components

Protect the receiver from high power transmitter

Receiver Front End



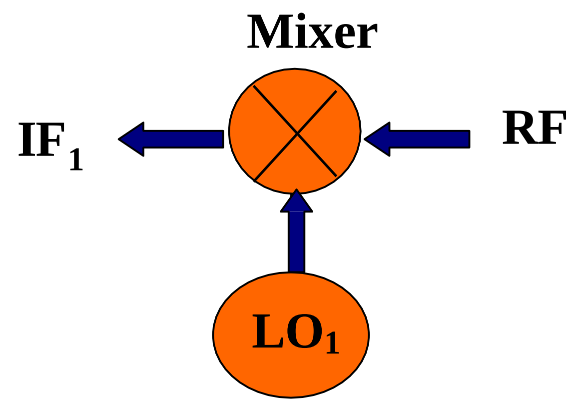
The radar *front end* consists of:
Bandpass filter or **bandpass amplifier**
LNA
Downconverter

The mixer itself and the preceding circuits are generally relatively broadband.

Tuning of the receiver, between the limits set by the **preselector or mixer bandwidth**, is accomplished by **changing the LO frequency**

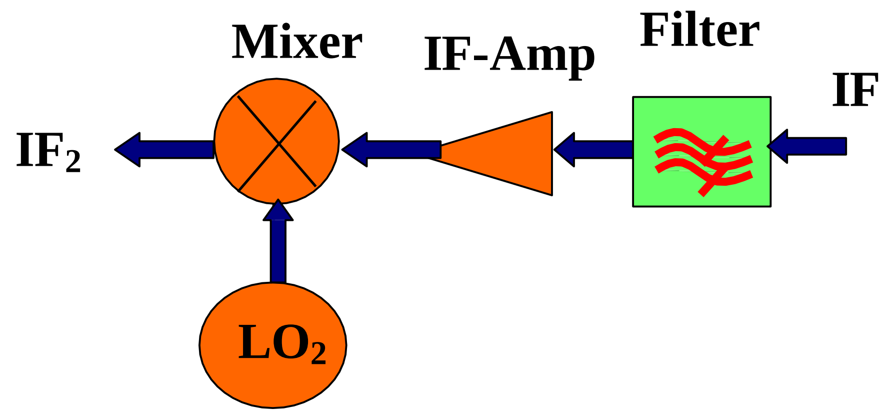
Superheterodyne principle is commonly used in radar receiver

More than one conversion step may be necessary to reach the final IF



IF range (0.1 and 100 MHz) without encountering serious image- or spurious-frequency problems in the mixing process.

At IF:
Amplification less costly
More stable than at microwave frequency
Simple filter operation



These advantages have been sufficiently powerful that competitive forms of receivers have virtually disappeared; only the superheterodyne receiver will be discussed in any detail.

Receiver Function

The function of a radar receiver is to amplify the echoes of the radar transmission and to filter them in a manner that will provide the maximum discrimination between desired echoes and undesired interference.

The interference comprises:

- Energy received from galactic sources
- Energy received from neighboring radars
- Energy received from neighboring communication systems
- Energy received from possibly jammers
- Noise generated in the radar receiver
- The portion of the radar's own radiated energy that is scattered by undesired targets (such as rain, snow, birds, and atmospheric perturbations)

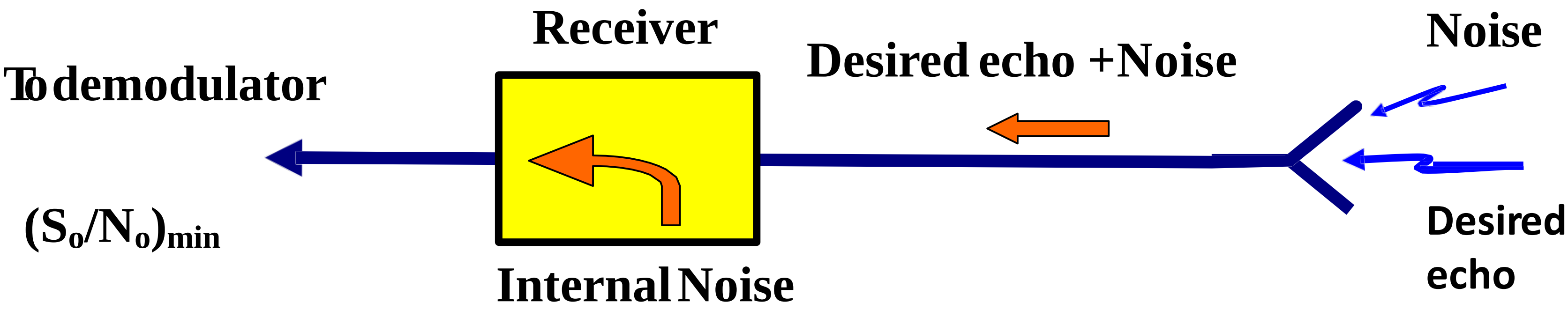
In airborne radars are used for altimeters or mapping:

- Ground is the desired target
- Other aircraft are undesired targets

More commonly, radars are intended for detection of

- Aircraft
- Ships
- Surface vehicles

Noise and Dynamic Range Considerations



Receivers **generate internal noise** which masks weak echoes being received from the radar transmissions. This noise is one of the fundamental limitations on the radar range

- The receiver is often the most critical component
- The purpose of a receiver is reliably recovering the desired echoes froma wide spectrum of transmitting sources, interference and noise
- Noiseis added into an RF or IF passband and degradessystem sensitivity
- Receiver should not be overloaded by strong signals

Noise Effects

Noise ultimately determines the threshold for the minimum echo level that can be reliably detected by a receiver.

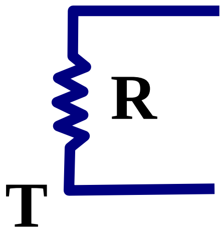
The receiving system does not register the difference between signal power and noise power. The external source, an antenna, will deliver both signal power and noise power to receiver. The system will add noise of its own to the input signal, then amplify the total package by the power gain

Noise behaves just like any other signal a system processes

Filters:	will filter noise
Attenuators:	will attenuate noise

Thermal Noise

The most basic type of noise being caused by thermal vibration of bound charges. Also known as Johnson or Nyquist noise.



$$\equiv \quad V_n = \sqrt{4KTBR}$$

Available noise power $\quad P_n = KTB$

Where, $\quad$ **K = Boltzmann's constant** $(1.38\times10^{-23}\,J/K)$

T $\quad$ **Absolute temperature in degrees Kelvin**

B $\quad$ **IF Band width in Hz**

At room temperature 290 K:

For 1 Hz band width, $\quad P_n = -174\,dBm$

For 1 MHz Bandwidth $\quad P_n = -114\,dBm$

Shot Noise:

Source: **random motion of charge carriers in electron tubes or solid state devices.**

Noise in this case will be properly analyzed on based on noise figure or equivalent noise temperature

Generation-recombination noise:

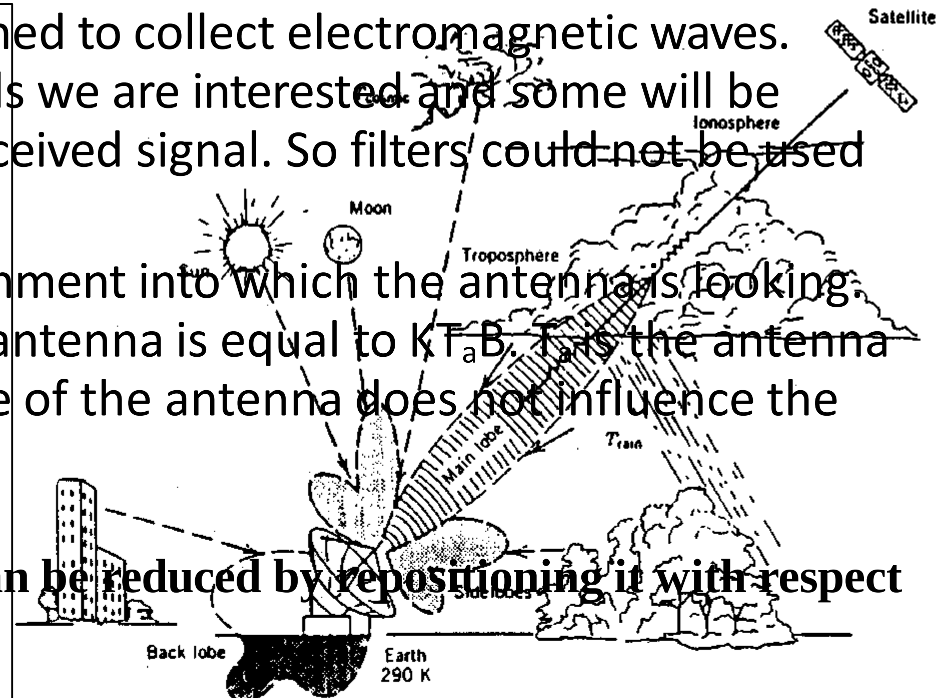
Recombination noise is the random generation and recombination of holes and electrons inside the active devices due to thermal effects. When a hole and electron combine, they create a small current spike.

Antenna Noise

In a receiving system, antenna positioned to collect electromagnetic waves. Some of these waves will be the signals we are interested and some will be noise at the same frequency of the received signal. So filters could not be used to remove such noise.

Antenna noise comes from the environment into which the antenna is looking. The noise power at the output of the antenna is equal to KT_aB. T_a is the antenna temperature. The physical temperature of the antenna does not influence the value of T_a.

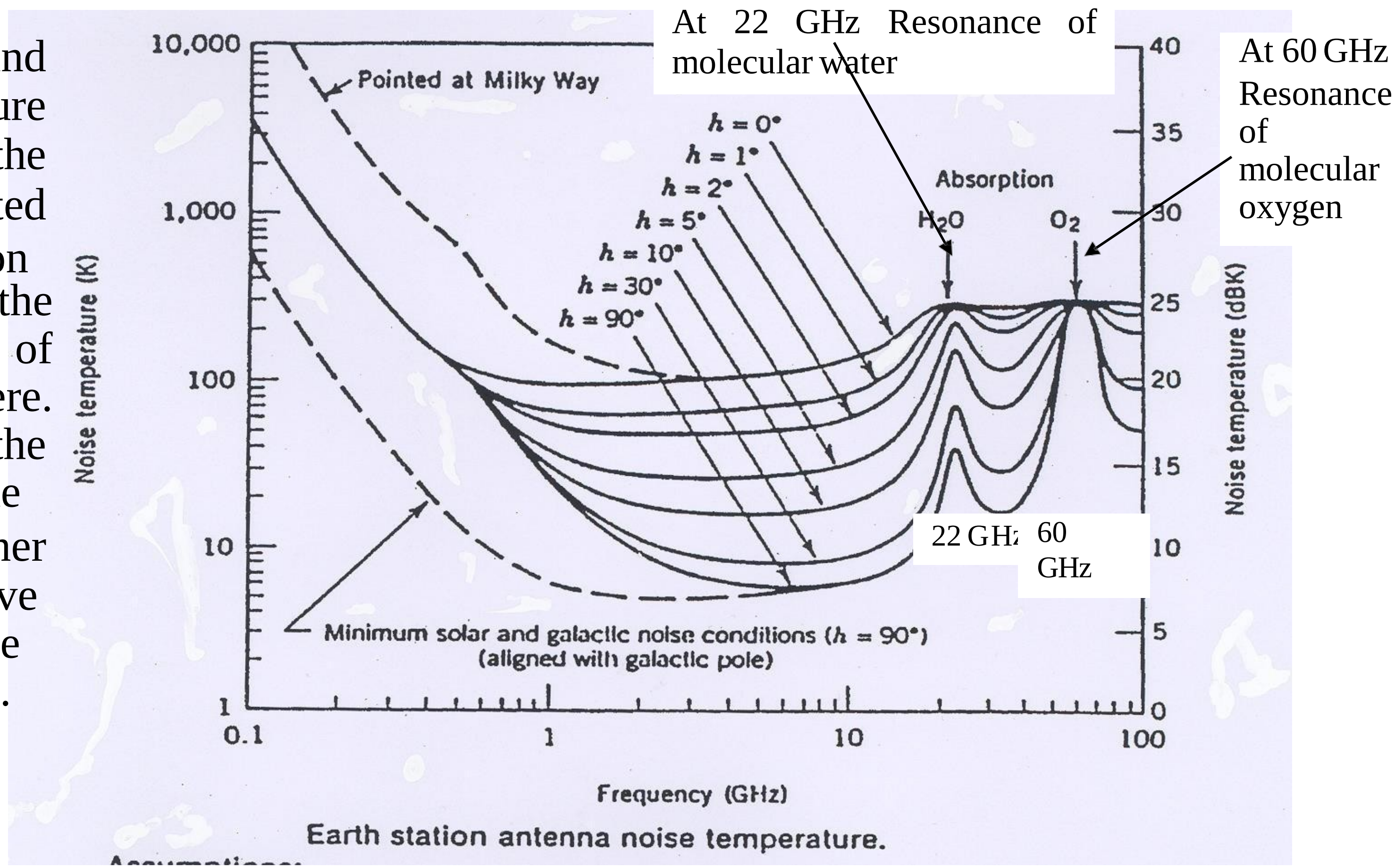
The noise temperature of the antenna can be reduced by repositioning it with respect to sources of external noise



Antenna noise temperature pickup

$$T_A = \frac{1}{\Omega_A} \oiint_{4\pi} F(\theta,\varphi) \cdot T_B(\theta,\varphi) d\Omega$$

The background noise temperature increases as the antenna is pointed toward the horizon because of the greater thickness of the atmosphere. Pointing the antenna toward the ground further increas the effective loss, and hence the noise temperature.



Assumptions

■ Antenna has no earth-looking sidelobes or a backtobe (zero ground noise)

■ Antenna is lossless ■ *h* is antenna elevation angle (degrees)

■ Sun not considered ■ Cool. temperate-zone troposphere

Equivalent Noise Temperature and Noise Figure

Noise Figure (F)

$F = (S/N)_i/(S/N)_o$

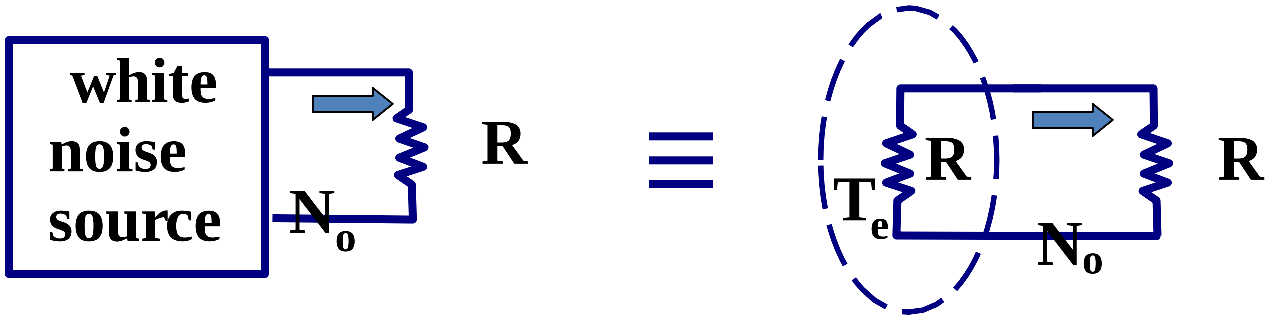
N_i = Noise power from a matched load at T_o = 290 K; N_i = KT_oB.

F is usually expressed in dB

F(dB)=10 log F.

Equivalent Noise Temperature (T_e)

If an arbitrary noise source is white, so that its power spectral density is not a function of frequency, it can be modeled as equivalent thermal noise source and characterized by T_e.



$T_e = N_o/KB$,

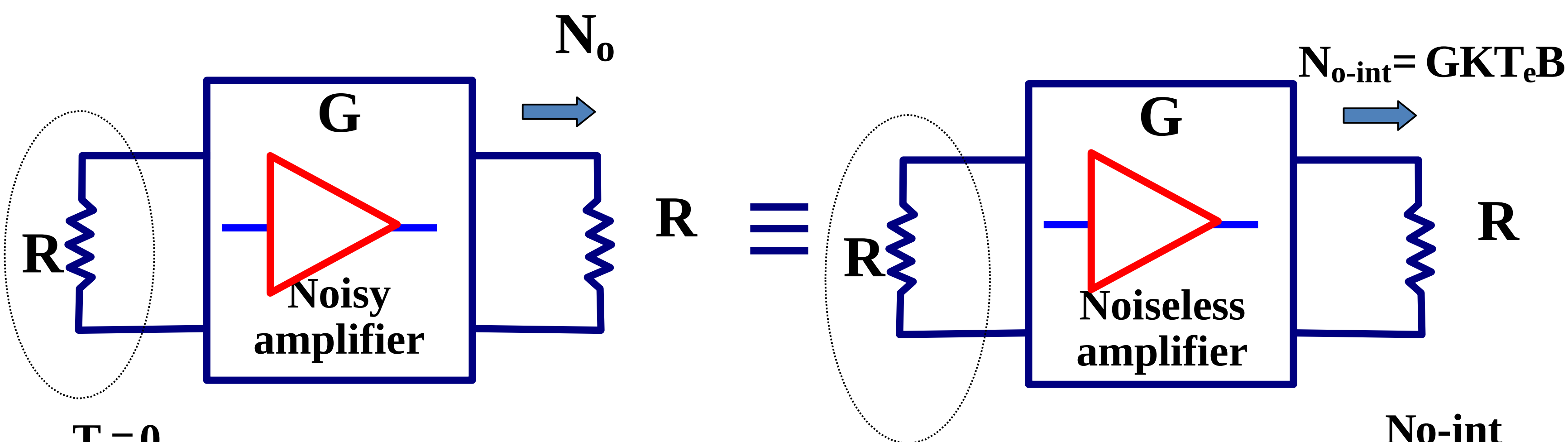
B is generally the bandwidth of the component or system

$T_e \geq 0$

If To is the actual temperature at the input port, usually 290 K

T_e may be greater or less than 290 K

Output Noise due to the internal noise of the receiver



T = 0

$$T_e = \frac{No\text{-}int}{GKB}$$

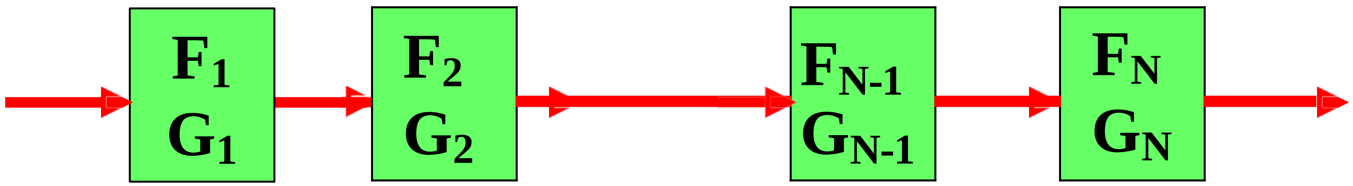
No $= N_{o\text{-int}}$ + **No$_{\text{-in}}$**

FGKT$_o$B $= GKT_eB$ + KT_oB

G

$$T_e = To(F-1) \qquad F = 1 + \frac{Te}{To}$$

Noise Figure of Cascaded Components



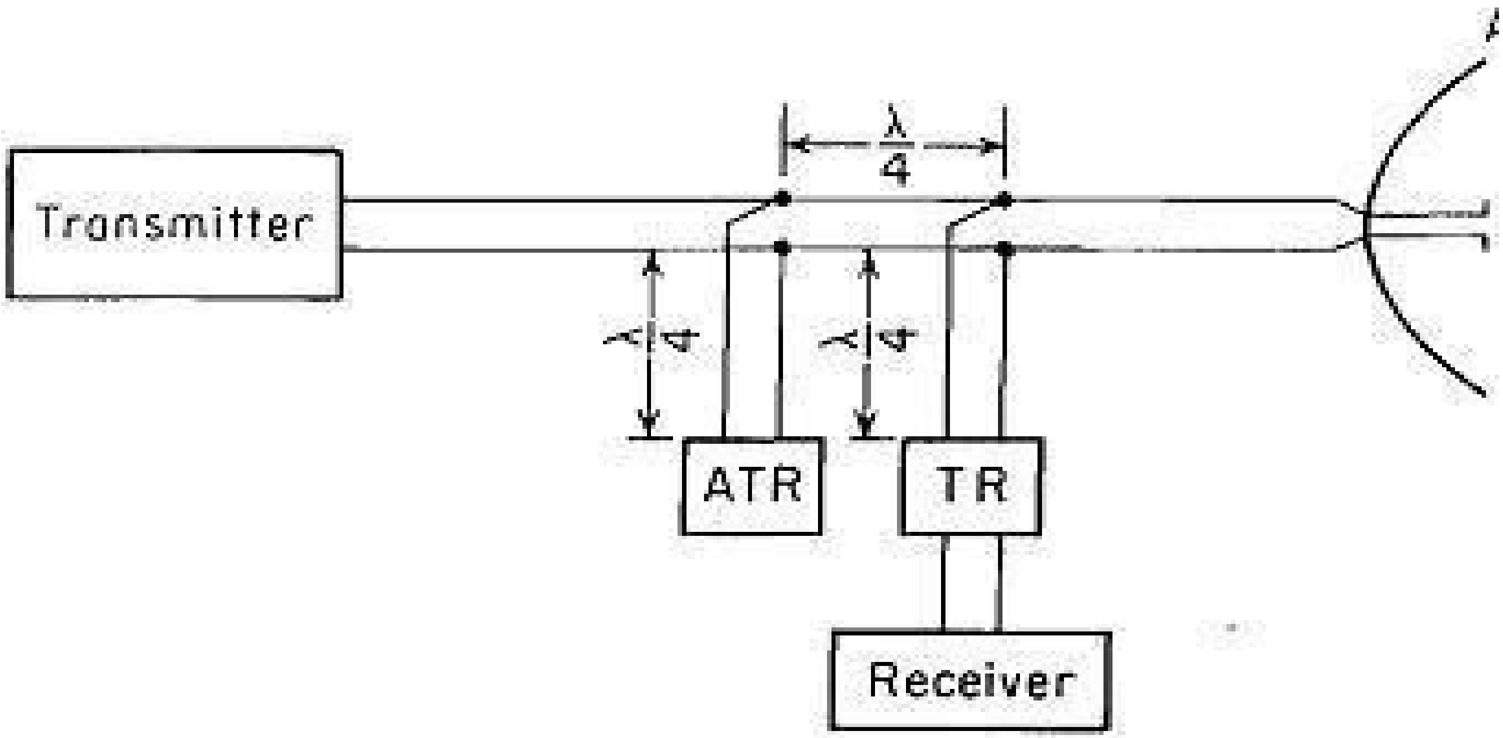
$$F_T = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots\ldots + \frac{F_n - 1}{G_1 G_2 \ldots\ldots G_{n-1}}$$

$T_e = T_o(F - 1)$

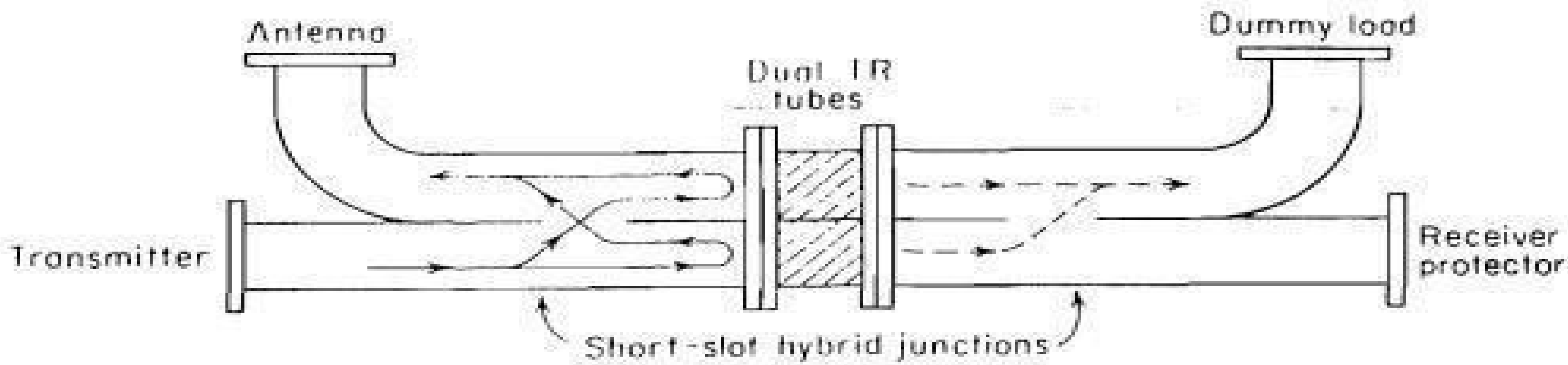
$T_s = T_a + T_e \quad \longrightarrow \quad P_n = KT_sBG,$

where, G is the overall gain of the system = $G_1 \times G_2 \times G_3 \ldots\ldots \times G_n$

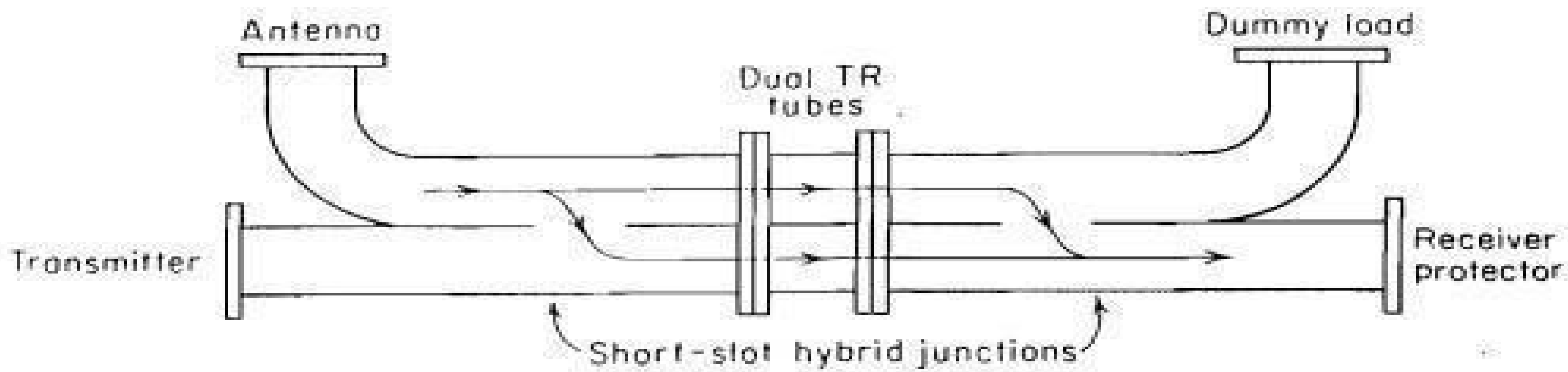
Branch-typeduplexers



Balancedduplexer

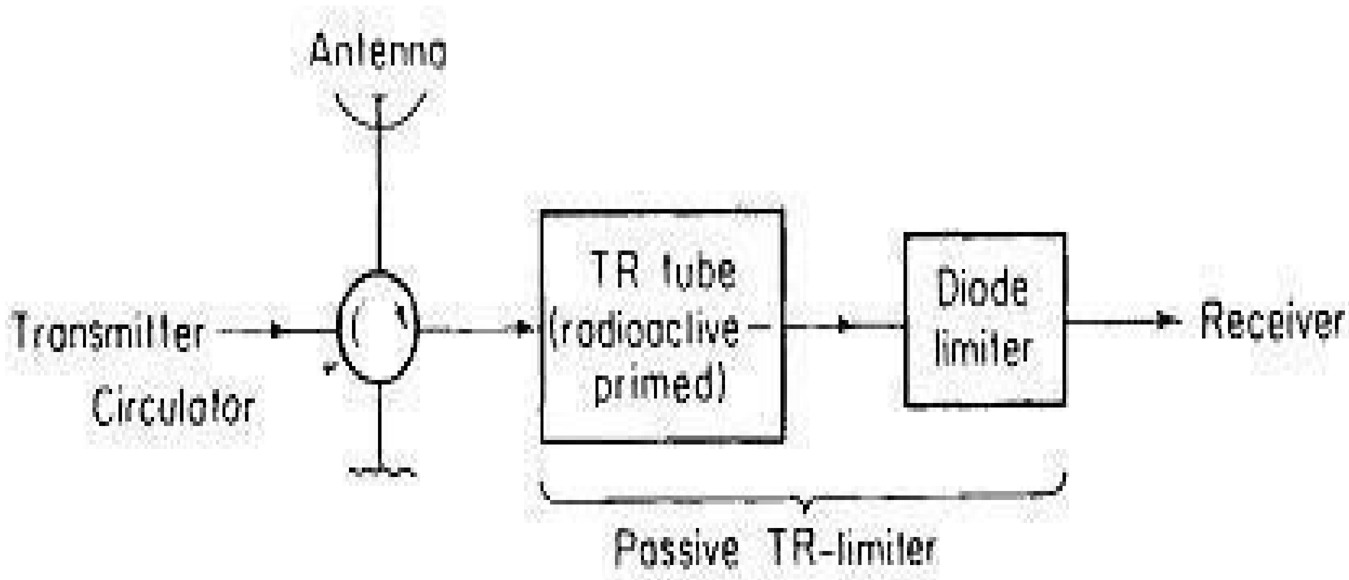


(a)



(b)

Circulator and receiver protector



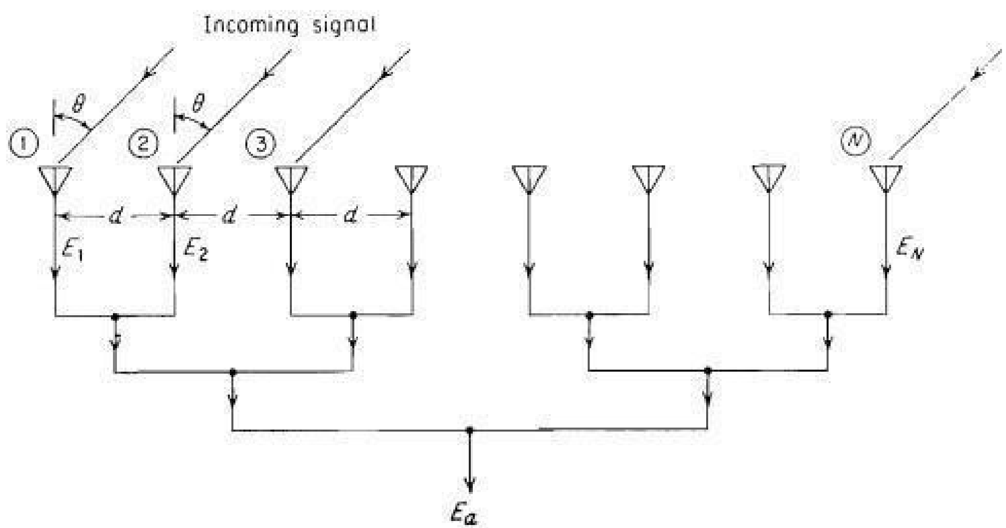
PHASED ARRAYANTENNA

Radiation pattern for Phased array Antenna

$$E_a = \sin \omega t + \sin (\omega t + \psi) + \sin (\omega t + 2\psi) + \cdots + \sin [\omega t + (N-1)\psi]$$

where ω is the angular frequency of the signal. The sum can be written

$$E_a = \sin \left[\omega t + (N-1)\frac{\psi}{2}\right] \frac{\sin (N\psi/2)}{\sin (\psi/2)}$$

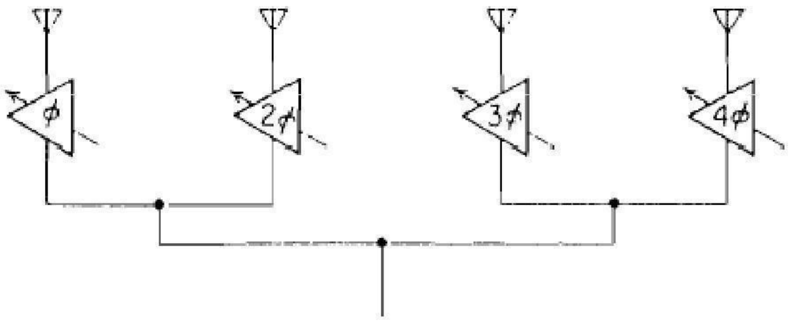


$$|E_a(\theta)| = \left| \frac{\sin [N\pi(d/\lambda) \sin \theta]}{\sin [\pi(d/\lambda) \sin \theta]} \right|$$

$$G_a(\theta) = \frac{|E_a|^2}{N^2} = \frac{\sin^2 [N\pi(d/\lambda) \sin \theta]}{N^2 \sin^2 [\pi(d/\lambda) \sin \theta]}$$

beam steering phased arrayantennas

$$G(\theta) = \frac{\sin^2 [N\pi(d/\lambda)(\sin \theta - \sin \theta_0)]}{N^2 \sin^2 [\pi(d/\lambda)(\sin \theta - \sin \theta_0)]}$$



Applications of phased array antennas

- ❖ Linear array with frequency scan
- ❖ Linear array with phase scan:
- ❖ Phase-frequency planar array:
- ❖ Phase-phase planar array

ADVANTAGESAND LIMITATIONS OF PHASED ARRAYANTENNAS.

Limitations:

- The major limitation that has limited the widespread use of the conventional phased
array in radar is its high cost, which is due in large part to its complexity.
- When graceful degradation has gone too far a separate maintenance is needed.
- When a planar array is electronically scanned, the change of mutual coupling that accompanies a change in beam position makes the maintenance of low side lobes
more difficult.
- Although the array has the potential for radiating large power, it is seldom that an
array is required to radiate more power than can be radiated by other antenna types
or to utilize a total power which cannot possibly be generated by current high-power microwave tube technology that feeds a single transmission line.