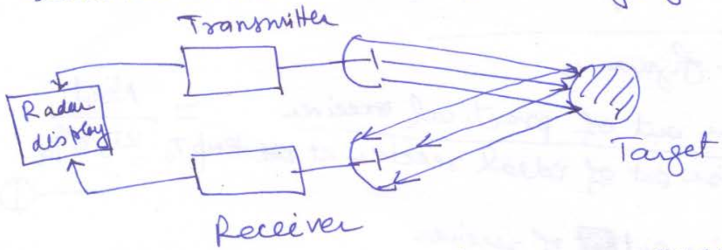
Q2 (a) Explain the basic principle of a radar system. Give limitations and applications of radars.

Answer

Principle:-

Q. 2. a. Radar is an electromagnetic system for detection and location of reflecting objects. It operates by radiating the energy into the space and detecting the echo signal reflected from an object/target. The reflected energy is returned to the radar indicating ~~the~~ presence of a object.



The transmitter generates an em waves/signal and radiate into space by antenne. A portions of transmitted energy is intercepted by target and radicted in many directions. The radiated energy directed back towards the radar is collected by antenna and received by receiver.

Limitations:-

1. Radars cannot resolve in detail like the human eye, especially at short distences.
2. They cannot recognise the color of the target.

Applications:-

A. Civilians Applications
1. Navigational aid on ground and see
2. Radar altimeters for determining the height of plane above ground.
3. Radar blind lander for aiding aircraft
4. Airborne radar for satelite surveilance.
5. Police radar directing and detecting speeding vehicles.
6. Speed of moving target

B. Military Applications
1. Detection and ranging of enemy targets
2. Aiming guns at aircraft and ship
3. Directing guided missiles.

Q2 (b) Calculate the maximum range of a radar system which operates with a peak pulse power of 600KW if its antenna is 5 m^2, minimum detectable signal is 10^{-13}W and radar cross-sectional area of the target is $20m^2$.

Answer

b. $\lambda = 3$ cm $\qquad \sigma = 20\,m^2$

$P_t = 600$ kW $\qquad R_{max} = ?$

$S_{min} = 10^{-13}$ W

$A_e = 5\,m^2$

$$R_{max} = \left(\frac{P_t A_e^2 \sigma}{4\pi \lambda^2 S_{min}} \right)^{\frac{1}{4}} = \frac{600 \times 10^3 \times 5^2 \times 20}{4\pi \times (3 \times 10^{-2})^2 \times 10^{-13}} = 717.65\text{ km}$$

Q3 (a) Derive an expression for maximum detectable signal to noise ratio.

Answer

3(a) The noise figure is

$$F_n = \frac{\text{noise out of practical receiver}}{\text{noise out of ideal receiver at std temp } T_0} = \frac{N_{out}}{K T_0 B G_a} \quad \text{— ①}$$

Where $N_{out} \rightarrow$ noise out of receiver

$G_a \rightarrow$ Available gain, $T_0 \rightarrow$ Standard temp.

$B \rightarrow$ Boltzmann constant

If $S_{in} \rightarrow$ Signal in and $S_{out} \rightarrow$ signal, Then available gain $G_a = \frac{S_{out}}{S_{in}}$

The input noise ~~out~~ of an ideal receiver $= k T_0 B$

The noise figure of eq. ① becomes

$$F_n = \frac{S_{in}/N_{in}}{S_{out}/N_{out}} \quad \text{— ②}$$

Re-arranging $S_{in} = \frac{F_n S_{out} N_{in}}{N_{out}} = \frac{k B T_0 F_n S_{out}}{N_{out}}$

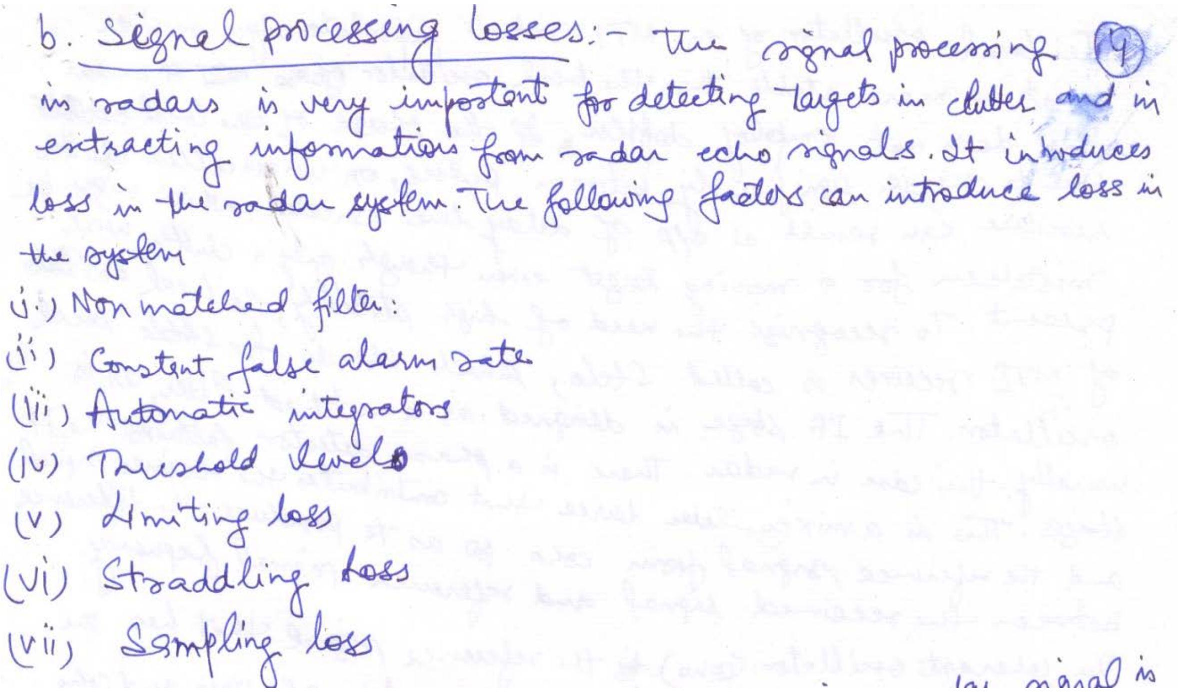
If minimum detectable signal S_{min} is correspond to $\left(\frac{S_{out}}{S_{in}}\right)_{min}$. i.e

$$S_{min} = k T_0 B F_n \left(\frac{S_{out}}{N_{out}}\right)_{min}$$

$$\therefore \boxed{(S_{min}) = k T_0 B F_n \left(\frac{S_{out}}{N_{out}}\right)_{min}}$$

Q3 (b) Briefly explain the signal processing losses in radar system.

Answer



b. Signal processing losses:- The signal processing ④ in radars is very important for detecting targets in clutter and in extracting informations from radar echo signals. It introduces loss in the radar system. The following factors can introduce loss in the system

(i.) Non matched filter:

(ii) Constant false alarm rate

(iii) Automatic integrators

(iv) Threshold levels

(v) Limiting loss

(vi) Straddling loss

(vii) Sampling loss

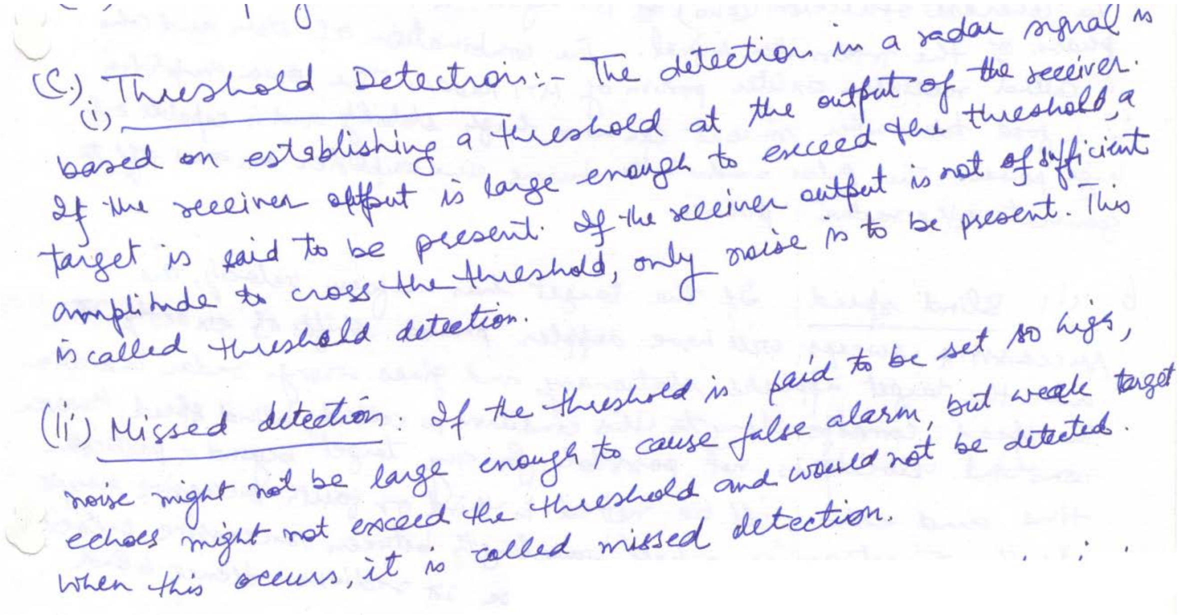
signal is

Q3 (c) Explain following in signal detection:

(i) Threshold detection

(ii) Missed detection

Answer



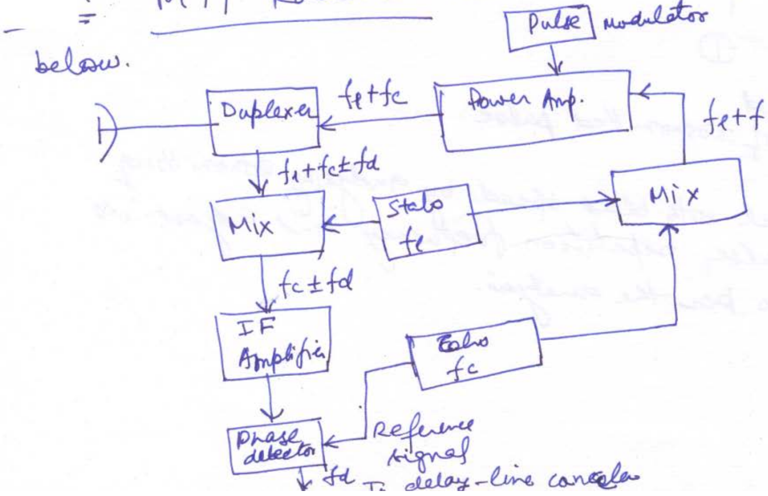
(c.) (i) Threshold Detection:- The detection in a radar signal is based on establishing a threshold at the output of the receiver. If the receiver output is large enough to exceed the threshold, a target is said to be present. If the receiver output is not of sufficient amplitude to cross the threshold, only noise is to be present. This is called threshold detection.

(ii) Missed detection: If the threshold is said to be set so high, noise might not be large enough to cause false alarm, but weak target echoes might not exceed the threshold and would not be detected. When this occurs, it is called missed detection.

Q4 (a) Explain the operation of MTI radar with the help of block diagram.

Answer

2. MTI Radar: The block diagram of MTI radar is given below.



The local oscillator of an MTI radar's superheterodyne receiver must be more stable than the local oscillator ~~of a~~ ~~MTI~~ a radar that does not employ doppler. If the phase of the local oscillator were to change significantly between pulses, an uncancelled clutter residue can result at o/p of delay line canceler which might be mistaken for a moving target even though only a clutter were present. To recognize the need of high stability, the local oscillator of MTI receiver is called Stalo, which stands for stable local oscillator. The IF stage is designed as a matched filter, as is usually the case in radar. There is a phase detector following the IF stage. This is a mixer-like device that contributes the receiver signal and the reference signal from coho so as to produce the difference between the received signal and reference signal frequency. The coherent oscillator (coho) ~~to~~ is the reference signal that has the phase of the transmitter signal. The combination of stalo and coho is called receiver-exciter portion of MTI Radar. The power amplifier ~~n~~ a good transmitter since it can have high stability and is capable of high power. The pulse modulator turns the amplifier on and off to generate the radar pulse.

Q4 (b) Write short notes on:

(i) Blind speeds

(ii) Doppler frequency shift

Answer

(i) Blind speed: If the target has uniform velocity, the successive sweeps will have doppler phase shifts of exactly 2π and the target appears stationary and gives wrong radar indicati The speed corresponding to this condition is called blind speed. However constant velocity is not possible for any target beyond a particular time and echo will be netted in third or fouth successive sweep If the target moves a half wavelength between successive pulses the change in phase shift will be 2π radians. Hence blind speed can be represented as

$$v_b = PRF \cdot \frac{n\lambda}{2} \quad ①$$

$v_b \rightarrow$ blind speed

$\lambda \rightarrow$ wavelength of transmitted pulse.

$n \rightarrow$ integer.

The target can travel with blind speed by analysing transmitting frequency and pulse repetition frequency and adjust its radial velocity as per the analysis.

b (ii) Doppler frequency Shift: - The doppler effect that ⑤ changes the frequency of em signal that propagates from radar to a moving target and back to the radar. If the target range is R, then total no. of wavelengths λ in two way path from radar to target and return is $2R/\lambda$. Each wavelength corresponds to a phase change of 2π radian. The total phase change in two way propagation path is then

$$\phi = 2\pi \cdot \frac{2R}{\lambda} = \frac{4\pi R}{\lambda} \quad \text{—①}$$

If target is in motion relative to radar, R is changing and so will the phase. Differentiate eq ① w.r.t time

$$\frac{d\phi}{dt} = \frac{4\pi}{\lambda}\frac{dR}{dt} = \frac{4\pi V_r}{\lambda} = 2\pi f_d \quad \text{—②}$$

where $V_r = \frac{dR}{dt}$ → radial velocity ∃

and $f_d = \frac{2V_r}{\lambda}$ → doppler frequency shift.

$$f_d = \frac{2V_r}{\lambda} = \frac{2f_1 V_r}{c} \quad \text{—③}$$

Q5 (a) Derive an expression for matched filter frequency response using Schwartz in-equality.

Answer

Q.5 a.

Derivation of the matched-filter frequency Response:-

The frequency response function of the linear, time invariant filter that maximizes the output peak-signal to mean noise ratio is

$$H(f) = G_a S^*(f) e^{-j2\pi f t_m} \quad \text{— ①}$$

When input noise is stationary and white. The ratio to be maximized is

$$R_f = \frac{|S_o(t)|^2_{max}}{N} \quad \text{— ②}$$

where $|S_o(t)|_{max}$ → Maximum value of o/p signal voltage

and N → Mean square noise power at o/p.

The magnitude of output voltage of a filter frequency response function is

$$|S_o(t)| = \left| \int_{-\infty}^{\infty} S(f)\, H(f)\, e^{j2\pi f t}\, df \right| \quad \text{— ③}$$

where S(f) → Fourier transform of I/P signal

The mean o/p noise power is

$$N = \frac{N_0}{2} \int_{-\infty}^{\infty} |H(f)|^2 df \quad \text{— ④}$$

where N_0 is input noise power per unit bandwidth.

Substituting eq ③ & ④ into eq 2. and $t = t_m \rightarrow$ time at which the o/p $|S_0(t)|^2$ is maximum

$$R_f = \frac{\left|\int_{-\infty}^{\infty} S(f)\, H(f)\, e^{j2\pi f t_m}\, df\right|^2}{\frac{N_0}{2}\int_{-\infty}^{\infty} |H(f)|^2\, df} \qquad \text{— ⑤}$$

Schwartz's inequality: If P and Q are two complex functions Then

$$\int P^* P\, dx \int Q^* Q\, dx \geq \left|\int P^* Q\, dx\right|^2 \qquad \text{— ⑥}$$

equality sign applies when $P = kQ$ $k \rightarrow$ constant

$P^* = S(f)\, e^{j2\pi f t_m}$ and $Q = H(f)$ —

$\int P^* P\, dx = \int |P|^2 dx$

using this application of Schwartz inequality, eq. ⑤ becomes

$$R_f \leq \frac{\int_{-\infty}^{\infty} |H(f)|^2 df \int_{-\infty}^{\infty} |S(f)|^2 df}{\frac{N_0}{2}\int_{-\infty}^{\infty} |H(f)|^2} = \frac{\int_{-\infty}^{\infty} |S(f)|^2 df}{N_0/2} \qquad \text{— ⑦}$$

Parseval's theorem: $\int_{-\infty}^{\infty} |S(f)|^2 df = \int_{-\infty}^{\infty} s(t)\, dt$ = signal Energy = E

$$\therefore \quad R_f \leq \frac{2E}{N_0} \qquad \text{— ⑧}$$

which states that o/p peak-signal to mean noise ratio from a matched filter depends only on the total energy of received signal and noise power per bandwidth. The frequency response function which maximises the peak signal to mean noise power ratio R_f is obtained using eq. 6 applies when $P = kQ$ or

$$H(f) = G_a S^*(f)\, e^{-j2\pi f t_m} \qquad \text{— ⑨}$$

where constant $k = 1/G_a$

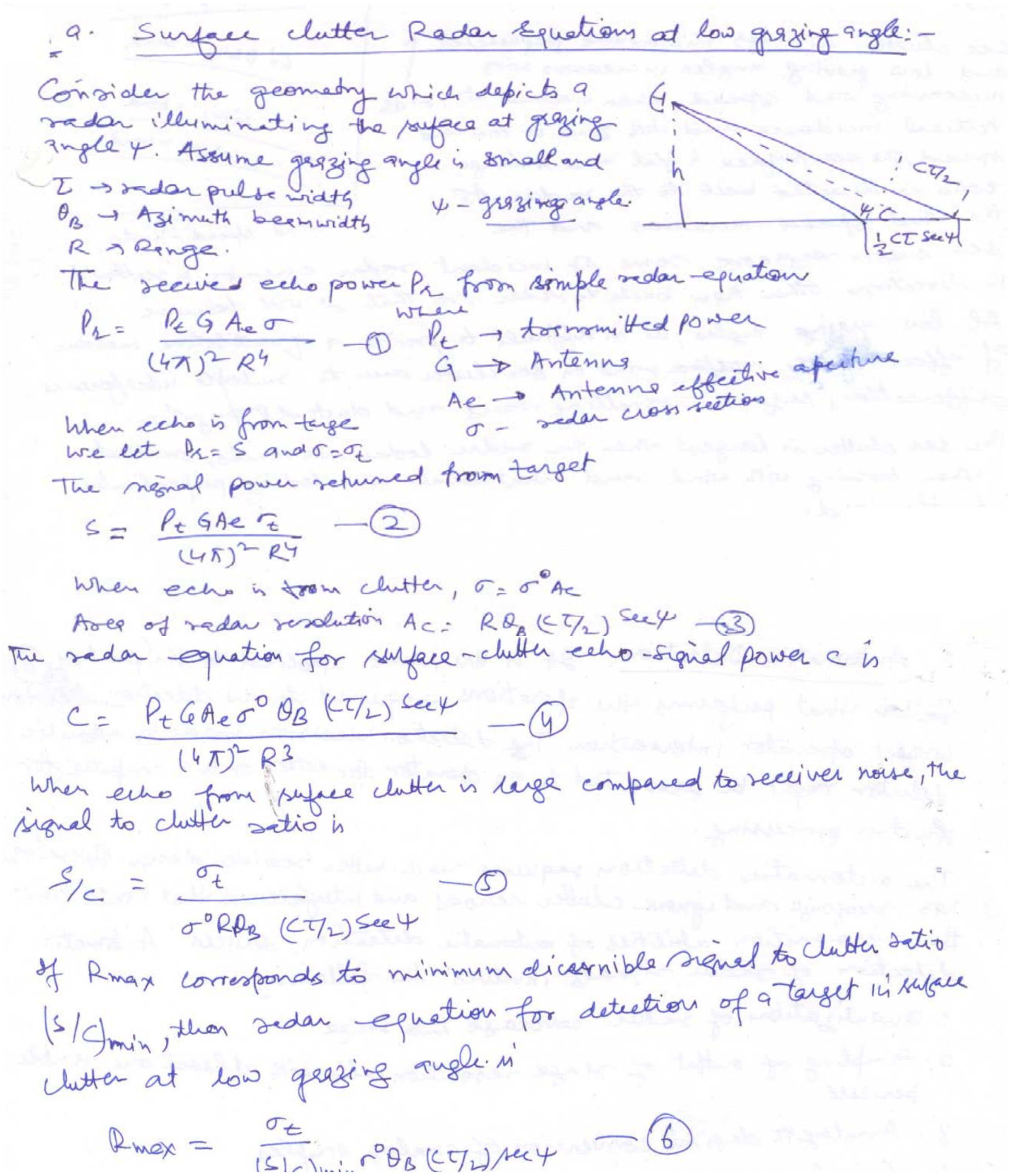
The eq ⑧ shows that the maximum ratio of the o/p peak-signal power to mean noise power is twice of energy E obtained in the received signal divided by noise power per unit bandwidth N_0.

Q5 (b) Explain I, Q detector with the help of block diagram.

Answer Page Number 288-289 of Text Book I

Q6 (a) Derive the radar equation for detection of a target in surface clutter at low grazing angle.

Answer



a. Surface clutter Radar Equations at low grazing angle:-

Consider the geometry which depicts a radar illuminating the surface at grazing angle ψ. Assume grazing angle is small and

τ → radar pulse width
θ_B → Azimuth beamwidth
R → Range.

ψ – grazing angle.

The received echo power P_r from simple radar-equation

$$P_r = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4} \quad — ①$$

where
P_t → transmitted power
G → Antenna
Ae → Antenna effective aperture
σ – radar cross section

When echo is from target we let $P_r = S$ and $\sigma = \sigma_t$

The signal power returned from target

$$S = \frac{P_t G A_e \sigma_t}{(4\pi)^2 R^4} \quad — ②$$

When echo is from clutter, $\sigma = \sigma^0 A_c$

Area of radar resolution $A_c = R\theta_B (c\tau/2) \sec\psi$ — ③

The radar equation for surface-clutter echo-signal power C is

$$C = \frac{P_t G A_e \sigma^0 \theta_B (c\tau/2) \sec\psi}{(4\pi)^2 R^3} \quad — ④$$

When echo from surface clutter is large compared to receiver noise, the signal to clutter ratio is

$$S/C = \frac{\sigma_t}{\sigma^0 R\theta_B (c\tau/2) \sec\psi} \quad — ⑤$$

If Rmax corresponds to minimum dicernible signal to clutter ratio $(S/C)_{min}$, then radar equation for detection of a target in surface clutter at low grazing angle is

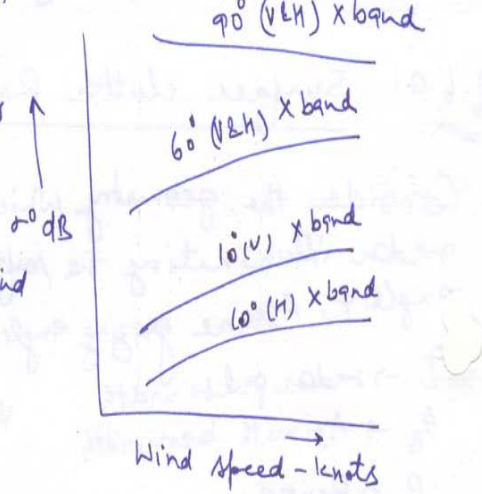
$$R_{max} = \frac{\sigma_t}{(S/C)_{min}\, \sigma^0 \theta_B (c\tau/2) \sec\psi} \quad — ⑥$$

Q6 (b) Explain the effect of wind on the magnitude of sea clutter.

Answer

6. Wind Effect on magnitude of see clutter:- The wind is the most important environmental factor that determines the magnitude of see clutter. At low grazing angles and microwave frequencies, backscatter from the see is quite low when wind speed is less than about 5kt. It increases rapidly with increasing wind from 5 to 20kt and increases more ~~rapi~~ slowly at higher wind speeds. At very high winds, the increase is small with increasing wind.

See clutter at high microwave frequencies and low grazing angles increases with increasing wind speed. When viewed at vertical incidence and with zero or low wind speed, the see surface is flat and a large echo is directed back to the radar. As the wind speed increases and the see surface roughens, some of incident radar energy is scattered in directions other than back to radar so that σ° will decrease.



At low grazing angles, it is difficult to provide a quantitative measure of effect of the ~~surface~~ wind on see clutter due to multiple interference, diffraction, surface travelling waves and ducted propagation.

The see clutter is largest when the radar looks into winds, smallest when looking with wind and intermediate when looking perpendicular to the wind.

Q7 (a) Define the directive gain, power gain and aperture efficiency of radar antenna.

Answer

⑦

7. a **Directive gain:-** It is measure of ability of an antenna to concentrate the transmitted energy in a particular direction.

$$G_D = \frac{\text{Maximum radiation Intensity}}{\text{average radiation Intensity}}$$

$$= \frac{4\pi\,(\text{maximum power radiated per unit solid angle})}{\text{total power radiated by antenna}}$$

$$= \frac{4\pi\, P(\theta,\phi)_{max}}{\iint P(\theta,\phi)\, d\theta\, d\phi} = \frac{4\pi}{B} \simeq \frac{4\pi}{\theta_B \phi_B}$$

where $B = \dfrac{\iint P(\theta,\phi)\, d\theta\, d\phi}{P(\theta,\phi)_{max}}$ is beam area.

ϕ_B & θ_B are half power beamwidth in two orthogonal planes.

Power gain: It is similar to directive gain except it takes account of dissipative losses in the antenna.

$$G = \frac{4\pi\,(\text{maximum power radiated per unit solid angle})}{\text{net power accepted by antenna}}$$

$$= \frac{\text{Maximum radiation intensity from subject antenna}}{\text{radiation intensity from lossless isotropic radiation with same power i/p}}$$

$= \rho_r G_D$ where $\rho_r \rightarrow$ radiation efficiency.

Aperture efficiency: It is based on the maximum radiation intensity which occurs at the centre of the main beam. The aperture efficiency less than unity means that energy is ~~but~~ redistributed in angle rather than be dissipated.

Q7 (b) Why does a parabolic surface make a good reflector antenna? Explain feeds for paraboloids.

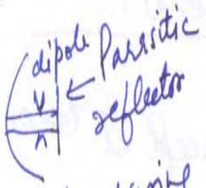
Answer

b. Feeds for Paraboloids:- The feed for a paraboloid reflectors would be source at the focus with a radiation pattern that

1. had no phase variation with angle
2. produced on the reflector surface the desired aperture amplitude illumination
3. had a directivity that allowed all the feed radiation to be intercepted by the aperture without spillover. The radiation pattern produced by feeds is called the primary pattern and that radiated by the aperture is called the secondary pattern.

A simple half-wave dipole with a parasitic reflector to direct most of its energy towards the antenna aperture can be used as the feed for a paraboloid. A dipole is of limited utility as a reflector feed since it is difficult to shape the primary pattern and it is limited in power handling at higher frequencies.

When more directivity is required from the feed than is available from open ended waveguide, horn form of wave guide can be used.



Rear feed using half wave dipole

rear feed using horn

front feed using horn.

Q7 (c) List the functions of a radar antenna.

Answer

C. Features of radar Antenna:- Radar Antenna serves the following features:-

1. Acts as the transducer between propagation in space and guided wave propagation in transmission lines.
2. Concentrates the radiation energy in the direction of the target
3. collects echo energy scattered back to radar from target
4. Measures the angle of arrival of the received echo signal.
5. Acts as spatial filter to separate targets in the angle domain and rejects undesired signals from direction other than main beam.
6. provides the desired volumetric coverage of radar.
7. establishes the time b/w radar observations of a target.

Q8 (a) Show that when a receiver of noise figure f_r is attached to an antenna with antenna temperature T_a, the system noise figure is $f_s = \frac{T_a}{T_o} + f_r$

where T_o is standard temperature 290 K.

Answer

Q.8 a. The noise introduced by a network is expressed as the effective noise temperature T_e and defined as the temperature at the input of the network that accounts for additional noise ΔN at the output. Therefore $\Delta N = kT_eB_nG$. $\Rightarrow T_e = \frac{\Delta N}{kB_nG}$ — ① ⑧

Also, noise figure $F_n = \frac{kT_0B_nG + \Delta N}{kT_0B_nG} = 1 + \frac{\Delta N}{kT_0B_nG} = 1 + \frac{T_e}{T_0}$ — ②

or $(F_n - 1)T_0 = T_e$ — ③

The system noise temperature T_s is defined as the effective noise temperature of the receiver including the effects of antenna temperature T_a. If the receiver effective noise temperature is T_e

$T_s = T_a + T_e$ — ④ using eq. 3, we get

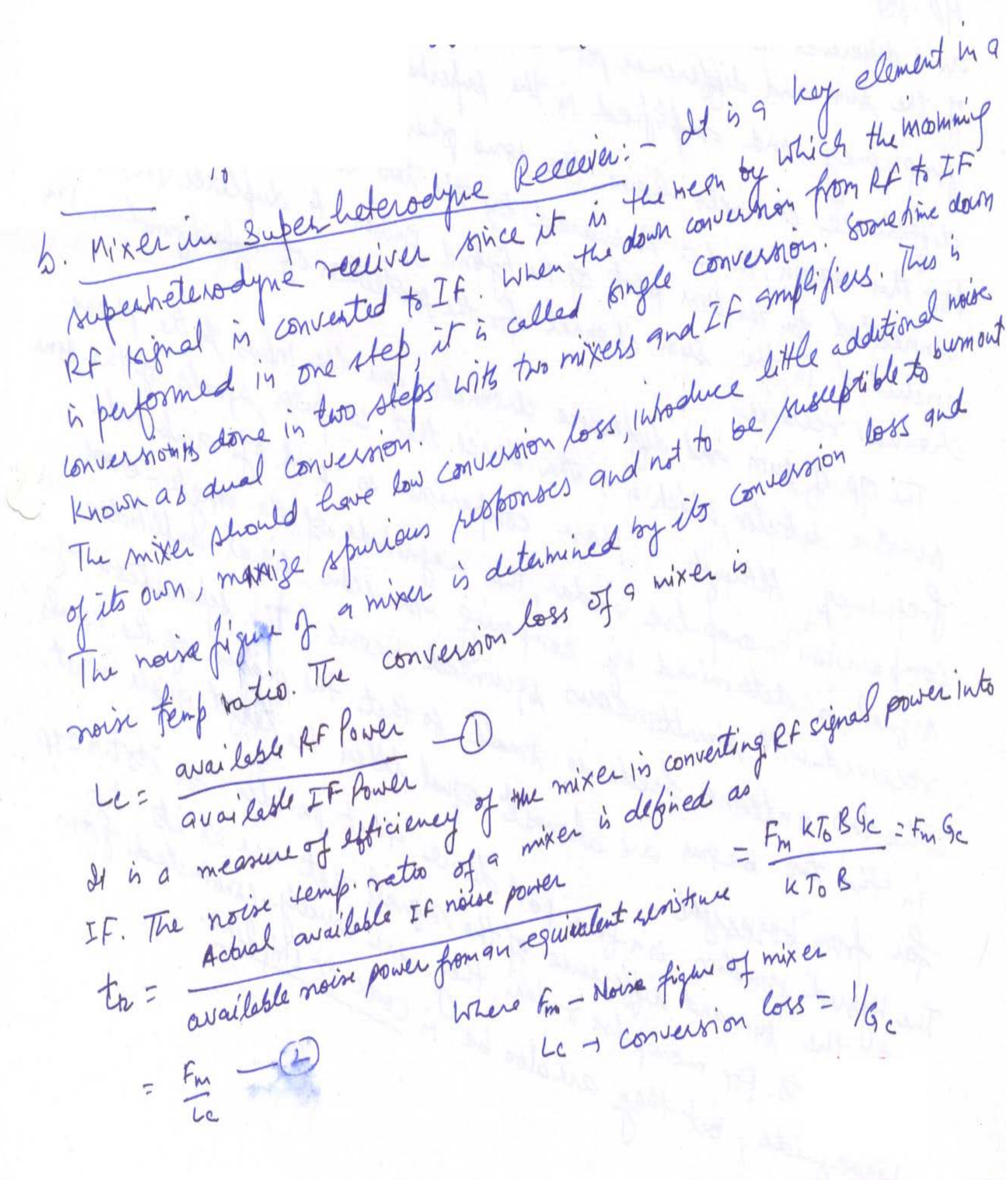
$\therefore T_s = T_a + (F_n - 1)T_0$

$\therefore$ System noise figure $F_s = \left(\frac{T_s}{T_0} + 1\right) = F_s = \left(\frac{T_a}{T_0} + F_n - 1\right) + 1$

$\therefore F_s = \frac{T_a}{T_0} + F_n$ — ⑤

Q 8 (b) Explain the types of mixer in a super heterodyne receiver.

Answer



b. Mixer in Superheterodyne Receiver:- It is a key element in a superheterodyne receiver since it is the mean by which the incoming RF signal is converted to IF. When the down conversion from RF to IF is performed in one step, it is called single conversion. Sometime down conversion is done in two steps with two mixers and IF amplifiers. This is known as dual conversion.

The mixer should have low conversion loss, introduce little additional noise of its own, maxize spurious responses and not to be susceptible to burnout.

The noise figure of a mixer is determined by its conversion loss and noise temp ratio. The conversion loss of a mixer is

$$L_c = \frac{\text{available RF Power}}{\text{available IF Power}} \quad ①$$

It is a measure of efficiency of the mixer in converting RF signal power into IF. The noise temp. ratio of a mixer is defined as

$$t_r = \frac{\text{Actual available IF noise power}}{\text{available noise power from an equivalent resistance}} = \frac{F_m k T_0 B G_c}{k T_0 B} = F_m G_c$$

$$= \frac{F_m}{L_c} \quad ②$$

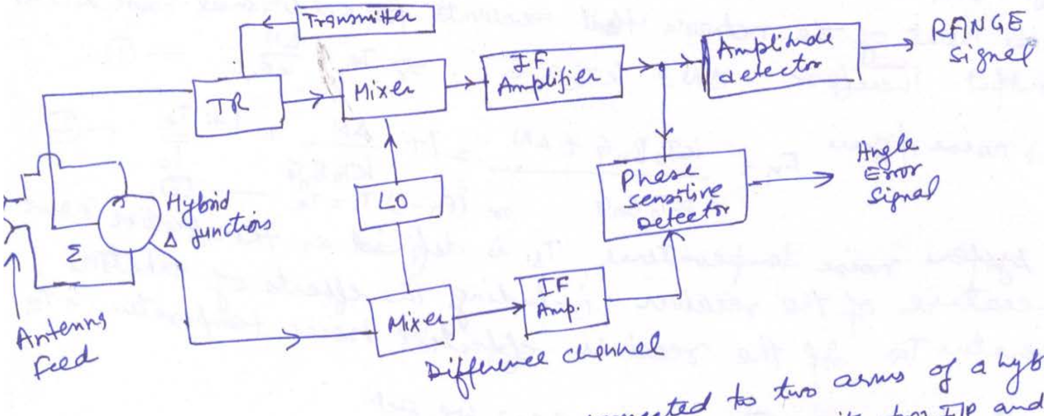
Where F_m – Noise figure of mixer

$L_c \rightarrow$ Conversion loss $= 1/G_c$

Q9 (a) What is amplitude- comparison monopulse tracking radar? Explain its operation with simple block diagram.

Answer

Q.9a. Amplitude - Comparision Monopulse tracking Radar:-



Two adjascent antenna feeds are connected to two arms of a hybrid junction, which is a four port microwave device with two I/P and two O/P ports. When two signals are inserted at two I/P ports, the sum and difference of two are found at the two O/P posts. On reception, the O/P of the sum and difference ports are each heterodyned to an intermediate frequency and amplified in the superheterodyne receiver. The sum and difference channels have the same phase and amplitude characteristics. For this reason, the LO is shared by the two channels. The transmitter is connected to the sum port of the hybrid junction. A duplexer (TR) is included in the sum channel for the protection of ~~hybrid junction~~ sum channel receiver.

The O/P of sum and difference channels are the inputs to the phase sensitive detector, which is another device that computer signals of the same frequency. Although a phase comparision is part of amplitude comparision monopulse radar, the magnitude of the angle-error signal is determined by comparing the echo-signal amplitudes received with simultaneous squinted beams. The separation of the two antenna feeds is small so that the phases of the signals in the two beams are almost equal when the target angle is not far from boresight.

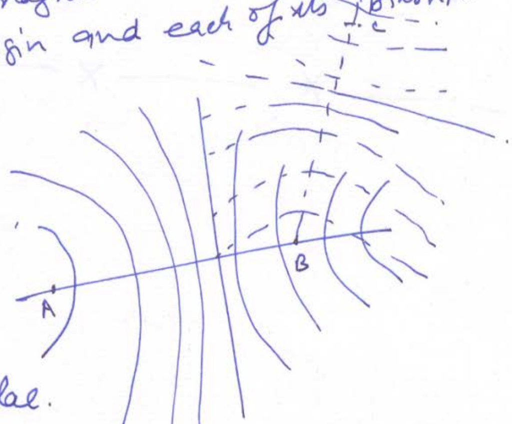
The hybrid junction is a four port device that provides at its two O/P ports the sum and difference of the signals that are at its two input ports. For monopulse radar, they are usually constructed from waveguide; but they are also be in coax or stripline.

Q9 (b) Explain the operation and applications of LORAN.

Answer

b. Long Range Navigational Aid (LORAN): It is a ⑨ hyperbolic system navigational aid which is used to guide the movement of a craft from one point to another along a desired path. Hyperbolic systems work on the principle of measurement of the difference in the time of arrival of em waves from two transmitters to the receivers in the craft. The locus of the points which have a constant value of such a difference in time is a hyperbola on a plane surface.

High power pulses are sent out from the two transmitting stations. The constant difference in the time of transmission ~~of~~ pulses from the two transmitters ~~ais~~ known. Thus time difference of the arrival of the pulses from two transmitters are observed on the receiver craft. The delay can be either positive or negative whose magnitude can't exceeded 2d/c. Where d is the distance b/w the origin and each of its transmitters at A and B. (fig 1)



$\frac{2d}{c}$ is the delay at all the points on the line joining A and B to the left A and to right of B. Measurement of the delay locates the craft on one of these hyperbolae.

The Accuracy depends upon
- Accuracy of measurement of the time interval
- Synchronization of transmitter stations
- Averaging the observation results.

Text Books

1. Introduction to Radar Systems, Merrill I. Skolnik, 3e, TMH, 2001

2. Electronic and Radio Engineering, F.E. Terman, McGraw Hill Publications.