RADAR

UNIT-ONE:

PRINCIPLES AND APPLICATIONS OF RADAR:

Questions Asked: 7

Que1 Derive free space radar range eq^n and discuss the various ways in which Range can be increased. (Derive eq^n ⑤ of second topic) (unit 1)

Que2 Explain with the help of block diagram the work of typical radar system. (unit 1)

Que3 Explain the influence of receiver noise figure on radar range. (unit 1)

Que4 Cal the max range of deep space radar operating at 2.5 GH$_z$ & using peak pulse power 25 MW. The antna dia is 64m. The target cross-section is 1m^2. The receiver noise figure = 1.1 and BW = 5KH$_z$ (unit 1)

Que5 what is Doppler effect ? Explain with help of diagram the working of FMCW radar (unit 2)

Que6 with help of block diagram explain opeᵒⁿ of MTI system ? (unit 3) B!

Que7 with help of B.D explain oper^n CW doppler radar using intermediate frequency in receiver. (unit 2)

Que8 what is blind speech ? How are they reduced ?

Que9 Describe with sketch the conical scanning method of tracking and aquired target How this is an improvement over lobe switching.

THEORY

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ET/00/265

Introduction: Radar is an electromagnetic system for detection and location of objects by radio waves. The term RADAR is an abbreviation from Radio detection and ranging. It operates by transmitting particular types of waveform (for ex a pulse modulated sine wave form) and detects the nature of echo signal.

A radar operates exactly in same manner with an object or target replacing the ionized layer. If time taken by pulse of radio wave to travel to the target and return by T_R, then range R is given by :

$$\boxed{R = \frac{CT_R}{2}} \quad ①$$

where C is velocity of radio waves (speed of light).

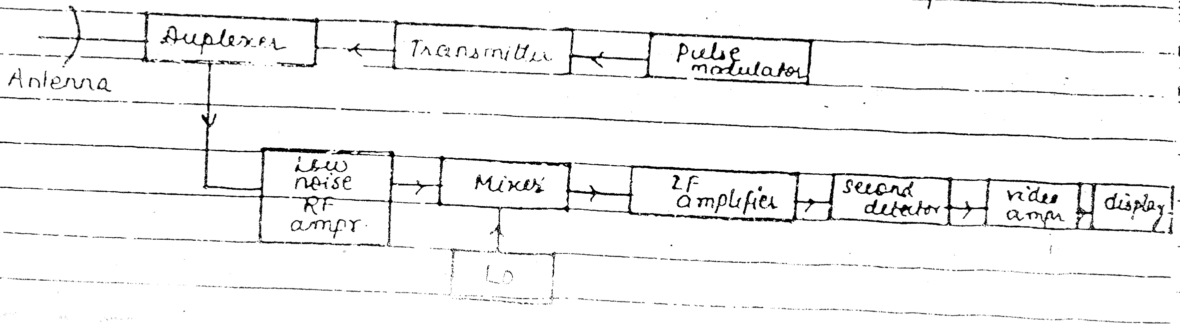
The factor 2 in denominator is due to the two way propagation of radio wave.

If range R is in (km) or in nautical miles (nmi) and the time T_R is in microseconds then eqn ① becomes

$$R(km) = 0.15\,T_r(\mu s).$$

~~R(0.081~~ $R(nmi) = 0.081\,T_R(\mu s).$

Block-diagram of pulse radar: The block diagram of typical pulse radar set is shown below. It's different blocks are explained below.



Blocks :

① Transmitter and modulator : The transmitter may be an oscillator like magnetron which is turned on and off (pulsed) by the modulator for generating repetitive train of pulses. ⑥

② Antenna : The electrical waveform generated by the transmitter travels through a transmission line or a waveguide to antenna wherefrom it is radiated into space as pulses of radio waves.

③ Duplexer : It protects the receiver from demage caused by the high ⑦ power of the transmitter and also serves to channel the returned echo signals to the receiver when the transmitter o/p is off. The duplexer might consists of two gasdischarge devices one known as transmit-receive (TR) & other known as Anti transmit receive ⑧ (ATR). The TR ~~dedects~~ protects the receiver during transmission and ATR directs the echo signal to receiver during reception.

④ Receiver : The receiver is of superheterodyne type. It consists of :-

① Low noise RF amplifier : To reduce the noise contribution of mixer a low noise RF ampr is used followed by a balanced mixer. In some applications it is excluded.

② Mixer and Local oscillator : The mixer and local oscillator convert the RF signal to an intermediate frequency IF. * R

⑤ IF amplifier : The IF amplifier amplifies the mixer output at the intermedicale frequency without producing appreciable distortion in pulse waveform of the IF signal. The BW of IF signal ampr should be ideally high (wide) for no envelope distortion of the IF signal. The IF ampr should be designed as a matched filter ie its frequency response function H(f) should maximize the peak

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signal-to-mean noise power ratio at output.

⑥ **Second detector:** The envelope of the IF signal is extracted by an envelope detector. A diode detector may be used for the purpose. However since the shape of the pulse envelope is important, to reduce distortion in pulse waveform the detector load is frequency compensated using different techniques.

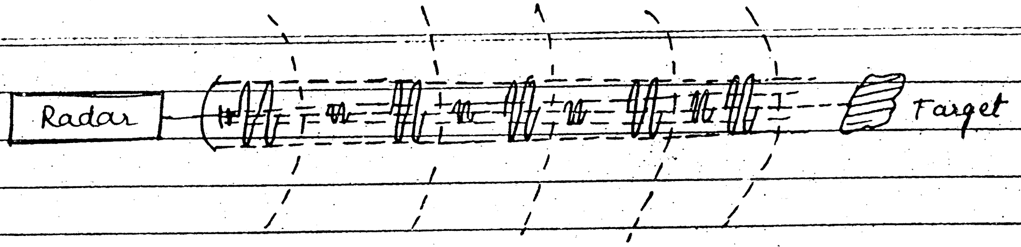
⑦ **Video amplifiers:** In this stage the detected echo signal is amplified in to a level so that it can be properly displayed on a cathode ray tube screen.

⑧ **Displays:** The simplest form of display is called the A-scope where the echo amplitude produces a deflection of e^- beam on CRO in y-dir^n.

Another type of display is called the B-scope which utilizes the rectangular coordinates to display range and elevation angle. Some other displays used are plan position indicator (PPI) and Range height (RH) display.

* **Radar Range eq^n:** The radar eq^n relates the range of radar to characteristics of the transmitter, receiver, antenna, target and environment. It is useful not just as means for determining the maximum distance from radar to the target but it can serve both a tool for understanding radar operation & its basis of design.

Derivation Let ① P_t = power of radar transmitter and if an isotropic ant^{na} is used then at distance R from radar power density is given by → power density from isotropic ant^{na} = $\frac{P_t}{4\pi r^2}$ —— ①



(pulse radar ranging)

② Radar employs directive ant^nas. Thus if G be transmitting gain G of antenna, the power density is given by :

$$\text{power density from directive ant}^{na} = \frac{P_t G}{4\pi R^2} \text{ ——— } ②$$

③ The target intercepts a portion of the incident power and reradiates it in various directions. The measure of amount of incident power intercepted by the target & ~~redi~~ reradiated back in dir^n of radar is denoted by radar crosssection σ & defined as

$$\text{Power density of echo signal at radar} = \frac{P_t G}{4\pi R^2} \frac{\sigma}{4\pi R^2} \text{ ——— } ③$$

* Ra

σ has units of area & it is a characteristic of particular target & measure of its size seen by radar.

④ If A_e by effective area of receiving ant^na, then Power received P_r is

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

⑤ The maximum radar range is (Rmax) distance, beyond which the target can't be detected. It occurs when the received echo signal power P_r just equal to minimum detectable signal Smin

$$\therefore \quad \cancel{R_{max}} \quad S_{min} = \frac{P_t G A_e \sigma}{(4\pi)^2 R_{max}^4}$$

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or $$\boxed{R_{max} = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}}\right]^{1/4}} \quad \text{——} \ ⑤$$

which is fundamental form of radar eq^n.
Also since gain $G = \frac{4\pi A_e}{\lambda^2}$ eq^n ⑤ becomes (put for A_e)

$$\boxed{R_{max} = \left[\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}}\right]^{1/4}} \quad \text{——} \ ⑥$$

and $$\boxed{R_{max} = \left[\frac{P_t A_e^2 \sigma}{4\pi \lambda^2 S_{min}}\right]^{1/4}} \quad \text{——} \ ⑦$$

Thus eq^{ns} ⑤, ⑥ & ⑦ are three different forms of radar eq^n.

*** Radar frequencies:** In general, radars are operated at frequencies in the range 220 MHz to 35 GHz. This is not necessarily the limit, since radars are operated outside this range. For example:

→ a ground wave HF radars might be operated at frequencies as low as 2 MHz.

→ Skywave HF over the ~~region~~ horizon (OTH) radar may be at frequencies as low as 4 or 5 MHz

~~→ groundwave HF radars as low as 2MHz.~~

→ Laser radars operate at even higher frequencies (GHz)

Table in next page shows standard radar frequency letter band nomenclature. Letter such as L, S, C etc are employed to designate radar frequency band.

Band	Frequency Range	Radarbands
HF	3-30 MHz	
VHF	30-300 MHz	138-144 MHz
		216-225 MHz
UHF	300-1000 MHz	420-450 MHz
		890-942 MHz
L	1000-2000 MHz	1215-1400 MHz
S	2000-4000 MHz	2300-2500 MHz
		2700-3700 MHz
C	4000-8000 MHz	5250-5925 MHz
X	8000-12000 MHz	8500-10680 MHz
Ku	12.0-18.00 GHz	13.4-14.0 GHz
K	18-26.5 GHz	24.05-24.25 GHz
Ka		33.4-36.0 GHz
mm	40-300 GHz	Q, U, V, E, W, F, D & G Bands

3> A
4> M
5> Re
6> Sp

lications of radar: The various applications of radars are given below:

1) **itary :** The major role of radar for military application has been for surveillance, navigation and also for control of guidance and weapons. It represents by far, the largest use of radar.

* P

2 **traffic control (ATC) :** Radars are used throughout the world for safety of aircrafts and controlling air traffic. It has been used with ground control approach (GCA) system for guiding aircraft to safe landing during distributed weather.

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3> **Aircraft Navigation:** Weather radars used on aircrafts to outline the precipitation regions to pilot in a classical form. Weather radars are also employed in airports to warn the pilot of thunderstorms. Besides these, radar is also utilized for terrain avoidance and terrain following during aircraft navigation.

4> **Marine Navigation:** Marine radars are used to enhance the safety of ship travel by warning about collision with other ships. Shore based radars are used for surveillance of harbours.

5> **Remote Sensing:** Remote sensing means sensing of geophysical objects or environment from a remote location. Thus radar has been used ~~for~~ to probe the moon & planets for some time. Remote sensing radars borne in satellites are now used for remote sensing of earthresources, water resources and environmental pollution.

6> **Space:** space vehicles have used radar for rendezvous and docking and for landing on moon. some of the ~~target~~ largest ground-based radars are for the detection & tracking of satellites.

*** prediction of Range performance:** The simple form of radar eq^n is given by

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

where, P_t = transmitted power in W, G = ant^{na} gain, A_e = ant^{na} effective aperture, (m^2), σ = radar cross-section (m^2), S_{min} = minimum detectable signal in Watts.

→ All the parameters are under the control of designer except for target cross-section σ.

→ The radar eq^n states that if long ranges are desired (i) the transmitted power must be large

(ii) the radiated energy must be concentrated into narrowbeam (for high gain)

(iii) the received echo energy must be collected with large antna aperture

(iv) receiver must be sensitive to weak signals.

However radar eqn given by ① does not predict range of performance to satisfactory degree of accuracy as eqn ① fails to include various losses that occur throughout the system.

An important factor that must be considered in the radar equation is statistical on unpredictable nature of several of parameters. The minimum detectable signal Smin and the target cross-section σ are both statistical in nature and must be expressed in statistical terms.

* Minimum detectable Signal:

Defination: The ability of radar receiver to detect a weak echo signal is limited by noise energy that occupies the same ~~energy~~ portion of frequency spectrum as does the signal energy. The weakest signal the receiver can detect is called minimum detectable signal. It is statistical in nature & hence its specification is ~~necessary~~ sometimes difficult.

Explaination: Detection is based on establishing threshhold level at the output of receiver. If the receiver output exceeds the threshold the signal is assumed to be present. This is called as "Threshold detection". The threshold level must be low if weak signals are to be detected, but it can not be so low that noise peaks cross the threshold and gives a false indication of presence

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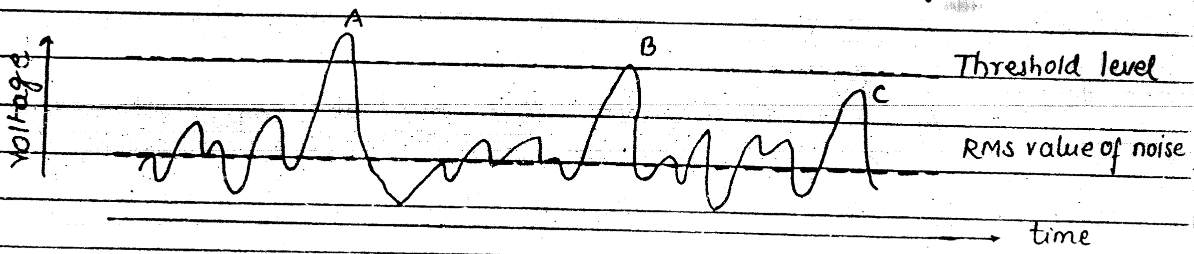
of target.

Now consider output of typical radar receiver as fn of time shown in fig(a). It is explained in following points :-



1) A theshold level is established as shown by dashed line.
2) A target is said to be detected if envelope crosses the threshold.
3) If a signal is large such as 'A' then it is not difficult to decide that target is present.
4) The noise voltage accompanying the signal at B is large enough so that the combination of signal plus noise exceeds the threshold.
5) At C noise is not as large & the resultant signal plus noise doesnot cross the threshold. Thus presence of noise sometimes will enhance the presence of detection of weak signal but it may also cause the loss of signal which would otherwise be detected.

Selection of threshold level: The selection of proper threshold level is compramise that depends upon how important it is if a mistake is made, either by <i> failing to recognize a signal that is present.
<ii> falsely indicating the presence of signal when none exists.

Signal to noise ratio: The S/N ratio necessary to provide adequate detection is one of the important parameter that must be determined in order to compute the minimum detectable signal. The advantage of considering $\frac{S}{N}$ ratio at IF is that assumption of linearity can be made.

It is also assumed that the IF filter characteristics approximates the matched filter so that the o/p S/N ratio is maximized.

* Receiver Noise :→

Introduction: Noise is an unwanted electromagnetic energy which interferes with ability of a receiver to detect the ~~un~~wanted signal.

It may originate (i) with in receiver itself.
(ii) it may enter via the receiving ant^na along with desired signal.

Even if noise due to above two factors are not present there would still exist an unavoidable component of noise generated by thermal motion of the conduction electrons & called as thermal and Johnson noise.

Range eq^n considering receiver noise: The available thermal-noise power generated by the receiver of bandwidth B_n (in Hz) at temp T°K is equal to

$$\boxed{\text{Available thermal noise power} = KTB_n} \quad \text{———} ①$$

where K = Boltzmann's constant = 1.38×10^{-23} J/deg. , T = 290K.

The bandwidth B_n is not 3-dB or half power BW but is integrated BW & is given by

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

where H(f) = frequency response char of IF amplifier
f_0 = frequency of maximum response.

*

The noise bandwidth B_n is an $\overset{\text{BW of}}{\wedge}$ equivalent rectangular filter whose noise power output is same as the filter with characteristic H(f).

Also, The noise figure F_n of receiver is defined as :

$$F_n = \frac{\text{noise o/p of practical receiver}}{\text{noise out of ideal rec. at temp } T_0} = \frac{N_0}{KT_0 B_n G_a} \quad \text{———} ③$$

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where N_0 = noise output from receiver & G_a = available gain. Also $T_0 = 290 K$.
The available gain G_a is the ratio of signal out S_o to signal in S_i and KT_0B_n is input noise N_i in ideal receiver ie

$$\boxed{N_i = KT_0B_n} \quad \text{—— ④}$$

~~Also~~ Now, noise figure F_n is also defined as ratio of i/p S/N ratio to output S/N ratio ie

$$\boxed{F_n = \frac{S_i/N_i}{S_o/N_o}} \quad \text{—— ⑤}$$

Thus from ⑤ and ④

$$S_i = F_n\left(\frac{S_o}{N_o}\right) \times N_i \quad \text{or} \quad S_i = KT_0B_nF_n\frac{S_o}{N_o} \quad \text{—— ⑥}$$

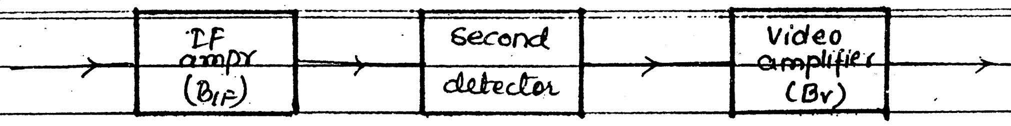
If the minimum detectable signal S_{min} is that value of s for which ratio $\left(\frac{S_o}{N_o}\right)_{min}$ of O/p (IF) signal to noise ratio is minimum (necessary for detection), then

$$\boxed{S_{min} = KT_0B_nF_n\left(\frac{S_o}{N_o}\right)_{min}} \quad \text{—— ⑦}$$

And thus radar range eqn can be given by eqn

$$\boxed{R_{max}^4 = \frac{P_tGA_e\sigma}{(4\pi)^2KT_0B_nF_n(S_o/N_o)_{min}}} \quad \left[\text{as } R_{max}^4 = \frac{P_tGA_e\sigma}{(4\pi)^2S_{min}}\right]$$

* **Signal to noise ratio:** The statistical noise theory can be conveniently applied to get the signal to noise ratio ~~of~~ at the o/p of IF amplifier. Consider the IF ampr with BW B_{IF} followed by a second detector and a video amplifier with bandwidth B_v. The video BW B_v must be greater than $B_{IF}/2$ in order to pass all the video modulation.



"Envelope detector"

The noise entering the IF amplifier is assumed to be Gaussian with probability-density function given by

$$\boxed{P(V) = \frac{1}{\sqrt{2\pi\psi_0}} \exp\frac{-V^2}{2\psi_0}} \text{ ——— ①}$$

where $p(v)dv$ is the probability of finding noise voltage v betn the values of v and $v+dv$, ψ_0 is the variance or mean square value of noise voltage and mean value of v is taken to be zero. If gaussian noise were passed through a narrowband IF filter - the probability density of the envelope of noise voltage output is shown by Rice to be

$$\boxed{P(R) = \frac{R}{\psi_0} \exp\left(-\frac{R^2}{2\psi_0}\right)} \text{ where ——— ②}$$

R is amplitude of envelope of filter o/p.

✓ Now the probability that the envelope of the noise voltage will lie between the values of V_1 and V_2 is

$$\text{Prob}\cdot(V_1 < R < V_2) = \int_{V_1}^{V_2} \frac{R}{\psi_0} \exp\left(\frac{-R^2}{2\psi_0}\right) dR \text{ ——— ③}$$

✓ The prob. that noise voltage envelope will exceed threshold voltage V_T is

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

$$= \exp\left(-\frac{V_T^2}{2\psi_0}\right) = P_{fa} \longleftarrow ④$$

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where P_{fa} is prob. of false alarm i.e. prob that noise will cross the threshold.

Also the average time interval between the crossings of the threshold by noise alone is defined as false alarm time T_{fa},

$$\boxed{T_{fa} = \underset{N \to \infty}{Lt} \frac{1}{N} \sum_{K=1}^{N} T_K} \text{ where} \quad \text{——— ⑤}$$

T_K is time between crossings of threshold V_T by noise envelope, when the slope of crossing is positive.

The false alarm prob. may also be defined as ratio of duration of time the envelope is actually above the threshold to total time it could have been above threshold T_{fa},

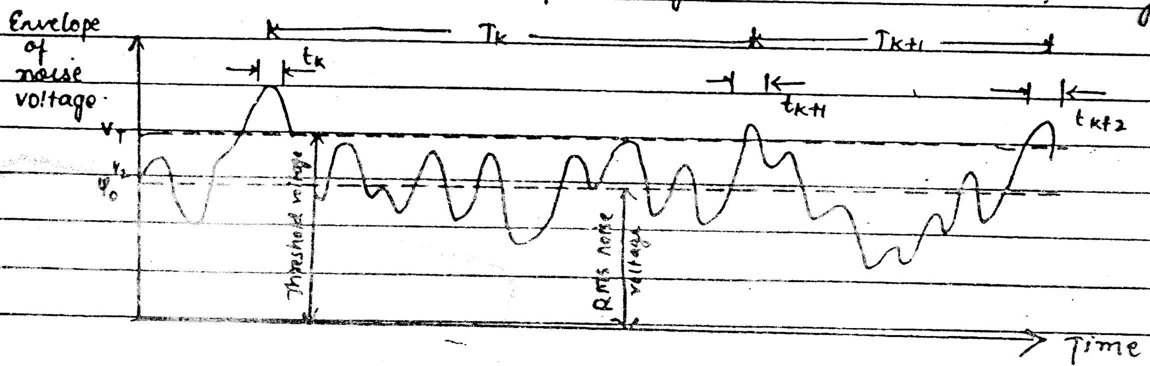
$$P_{fa} = \frac{Lt \sum_{K=1}^{N} t_K}{\sum_{K=1}^{N} T_K} = \frac{\langle t_K \rangle av}{\langle T_K \rangle av} = \frac{1}{T_{fa}B} \quad \text{——— ⑥}$$

Equating ⑥ and ④

$$\text{or} \quad \boxed{T_{fa} = \frac{1}{B_{IF}} \exp\left(+\frac{V_T^2}{2\psi_0}\right)} \quad \text{——— ⑦}$$

A plot of eq^n ⑦ is shown below with $\frac{V_T^2}{2\psi_0}$ as abscissa.

The false alarm prob. of practical radar is very small



If for example the BW of IF amplifier were 1 MHz and the average false alarm that could be tolerated were 15 min, the probability of false alarm is 1.11×10^{-9}.

Now consider the sine-wave signal of amplitude A to be present along with noise at input to the IF amplifier (filter). The frequency of signal is same as IF midband frequency f_{IF}. Thus output of envelope detector has Pdf given by

$$\boxed{P_s(R) = \frac{R}{\psi_0} \exp\left(-\frac{R^2+A^2}{2\psi_0}\right) I_0\left(\frac{RA}{\psi_0}\right)} \quad \text{— ⑧}$$

where $I_0(z) \approx \frac{e^z}{\sqrt{2\pi z}}\left(1 + \frac{1}{8z} + \cdots\right)$ is modified Bessel fn of zero order and argument.

* The probability that signal will be detected is same as prob. that envelope R will exceed v_T.

Thus

$$\boxed{P_d = \int_{v_1}^{\infty} P_s(R)\,dR = \int_{v_T}^{\infty} \frac{R}{\psi_0} \exp\left(-\frac{R^2+A^2}{2\psi_0}\right) I_0\left(\frac{RA}{\psi_0}\right) dR} \quad \text{— ⑨}$$

Using series approximation & assuming $\frac{RA}{\psi_0} >> 1$, $A >> |R-A|$ we get

$$P_d = \frac{1}{2}\left(1 - \operatorname{erf}\frac{v_T - A}{\sqrt{2\psi_0}}\right) + \frac{\exp[-(v_T-A)^2/2\psi_0]}{2\sqrt{2\pi}\,(A/\sqrt{\psi_0})}$$

$$\times \left\{1 - \frac{v_T - A}{4A} + \frac{1 + (v_T - A)^2/\psi_0}{8A^2/\psi_0}\right\} \quad \text{— ⑩}$$

where error fn is defined as

$$\operatorname{erf} z = \frac{2}{\sqrt{\pi}} \int_0^z e^{-u^2}\,du$$

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The signal to noise voltage ratio is $A/\psi_0^{1/2}$ in eqⁿ ⑩ may be expressed as:

$$\boxed{\frac{A}{\psi_0^{1/2}} = \frac{\text{signal amplitude}}{\text{rms noise voltage}}}$$

$$= \frac{\sqrt{2}\,(\text{rms signal voltage})}{\text{rms noise voltage}}$$

$$= \left(2\,\frac{\text{signal power}}{\text{noise power}}\right)^{1/2}$$

$$\boxed{\frac{A}{\psi_0^{1/2}} = \left(\frac{2S}{N}\right)^{1/2}} \quad \text{———⑪}$$

* Integration of radar pulses:

⑨ **Defination:** The target display on screen is not due to single pulse but due to summation of many pulses which are returned from any particular target on each radar scan and can be used to improve detection. Thus "~~purpose~~ of process of improving detection by summing all radar echo pulses is called integration".

The number of pulses n_B returned from a point target as radar antⁿᵃ scans through its BW is

$$n_B = \frac{\theta_B f_P}{\dot{\theta}_s} = \frac{\theta_B f_p}{6\omega_m} \quad \text{———①} \quad (\text{BW} \rightarrow \text{beam width})$$

⑩ where θ_B = antⁿᵃ beamwidth; f_p = pulse repetition freq, Hz; $\dot{\theta}_s$ = antenna scanning rate, deg/s; ω_m = antⁿᵃ scan rate, rpm.

Integration methods: Integration may be accomplished in radar receiver either before second detector & after second detector. The two methods are explained below:

Predetection integration	post detection integration
1) when integration is done before second detector (in IF) is is called predetection integration.	1) when integration is done after second detector (• in the video) it is called post detection integration.
2) It is coherent detection.	2) It is non coherent detection.
3) It requires that phase of echo signal be preserved if full benifit is obtained from summing process.	3) In post det-int., phase information is destroyed by second detector, hence is not concerned with preserving RF phase.
4) It is more efficient.	4) It is less efficient.
5) If n pulses all with same $\frac{S}{N}$ ratio were integrated by an ideal predetection integrator the resultant $\frac{S}{N}$ ratio would be exactly n times that of single pulse, hence high integration efficiency.	5) would be less than n times that of single pulse, due to non linear action of second detector hence low integration efficiency.
6) It is difficult & complicated to implement & hence is less preferred.	6) It is easier to implement in most applications hence instead of low efficiency it is most preferred.

Efficiency of post detection integration: The efficiency of post detection integration relative to predetection integration is given by 'Marcum' for all pulses of equal amplitude & is given by

$$\boxed{E_i(n) = \frac{(S/N)_1}{n(S/N)_n}} \quad \text{where} \quad \text{———} ②$$

n = no. of pulses integrated, $(S/N)_1$ = S/N for $n = 1$ pulse.

Integration improvement factor: The improvement in the signal to noise ratio when n pulses are integrated postdetection is $nE_i(n)$ and

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is called integration improvement factor.

Radar eqⁿ: The radar eqⁿ with n-pulses integrated can be written as

$$\boxed{R_{max}^4 = \frac{P_t G A_e \sigma}{(4\pi)^2 k T_0 B_n F_n (S/N)_n}} \quad \text{where} \quad \text{——} ③$$

$\left(\frac{S}{N}\right)_n$ is signal to noise ratio of n integrated pulses

Thus from ② and ③

$$\boxed{R_{max}^4 = \frac{P_t G A_e \sigma n E_i(n)}{(4\pi)^2 k T_0 B_n F_n (S/N)_1}} \quad \text{——} ④$$

* Radar cross-section of targets:

Defination: The radar cross section of a target is the area intercepting the amount of power which when scattered equally in all directions, produces an echo at radar equal to that of target; or in other terms;

$$\sigma = \frac{\text{Power reflected toward source/ unit solid angle}}{\text{incident power density}/4\pi}$$

$$\Rightarrow \sigma = \lim_{R\to\infty} 4\pi R^2 \left|\frac{E_r}{E_i}\right|^2 \quad \text{where}$$

R = distance betⁿ radar & target

E_r = reflected field strength at radar.

E_i = strength of incident field at target.

For most common types of radar targets such as aircrafts, ships etc the crosssection does not bear simple relationship to physical area except that larger the target size larger will be cross section.

Scattering and diffraction are variations of same physical process. when an object scatters an electromagnetic wave, the scattered field is defined as the difference betn total field in presence of the object & field that would exist if the object were absent.

while, the diffracted field is total field in presence of object. In theory the scattered field & hence radar cross-section can be determined by solving Maxwells eqns with proper boundary conditions applied.

*** Transmitter power:**

Introduction: As we know that the radar range eqn is given by

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

P_t = transmitted power in watts or peak pulse power.

① The peak pulse power is defined as the power averaged over the carrier frequency cycle which occurs at the maximum of the pulse of power. Peak Power is usually one-half of maxm instneous power. ② Also the average radar power Pav is defined as the average transmitter power over the pulse repetition period...

Explaination: Assuming that the transmitted waveform is a train of rectangular pulses of width τ & pulse repetition period $T_p = 1/f_p$, the average power is related to peak power by

$$\boxed{P_{av} = \frac{P_t \tau}{T_p} = P_t \tau f_p} \quad \text{——— ①}$$

The ratio $\frac{P_{av}}{P_t}$, $\frac{\tau}{T_p}$, or τf_p is called as duty cycle of radar.

→ Duty cycle = 0.001 for pulse radar for detection of aircraft
= 1 for CW radar.

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Now writing radar eqⁿ in terms of the average power rather than the power power we get

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

In most radar applications product $(B_n\tau) = 1$.

If the transmitted waveform is not a rectangular pulse, it is more convenient to express eqⁿ ② in terms of energy $E_t = \frac{P_{av}}{f_p}$ contained in transmitted waveform:

$$\therefore \boxed{R_{max}^4 = \frac{E_t G A_e \sigma n E_i(n)}{(4\pi)^2 K T_0 F_n (B_n\tau)(S/N)_1}} \quad \text{———} ③$$

Thus from ③ it is clear that range doesn't depend on either the wavelength or pulse repetition frequency. Also the imp parameters affecting range are
(i) total transmitted energy nE_t
(ii) The transmitting gain G.
(iii) Effective receiving aperture A_e.
(iv) Receiver noise figure F_n.

* Pulse repetition frequencies & Range Ambiguities:

Introduction: The pulse repetition frequency (prf) is ~~determined~~ primarily determined by maximum range at which targets are expected. If prf is too high the probability of obtaining target echoes from ~~long~~ wrong pulse transmission is increased.

Echo signals received after an interval exceeding prf is pulse repetition period are called multiple-time around echoes. They can result in erroneous or confusing range measurements.

Explaination: consider three targets A, B & C as shown in fig(a).

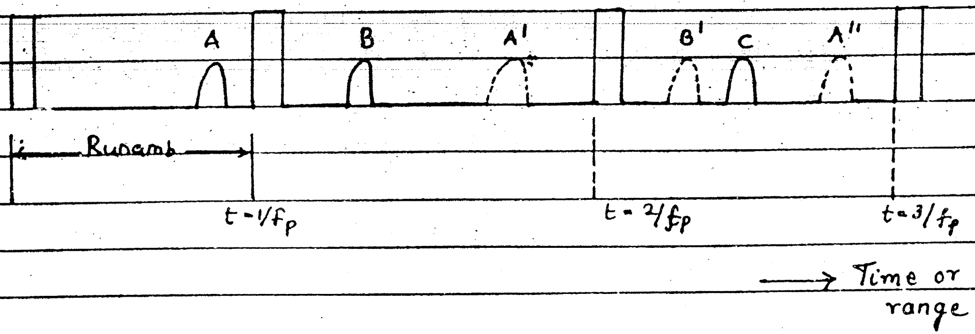
As shown:

→ Target A is located with maximum unambigous range Runamb of radar given by eq^n Ⓐ of perevious topic.

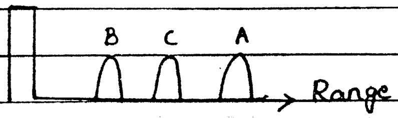
→ Target B is located at distance greater than Runamb & smaller than 2Runamb.

→ Target C is located at distance greater than 2Runamb but less than 3 Runamb.

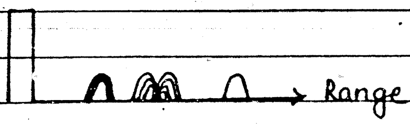
fig(a) →



fig(b) →



fig(c) →



As shown in fig(b) the three targets as appeared on A-scope. The range measured for target A is correct those for B and C are not.

Method for distinguishing multiple time around echoes: The method of distinguishing multiple time around echoes from unambigous

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echoes is to operate with varying prf. The echosignal from an unambigous range target will appear at same place on A-scope on each sweep no matter whether the prf is modulated or not. However the echoes from multiple time around targets will be spread over finite range as shown in fig(c). The prf may be changed continously within prescibed limits or it may be changed discretely among several pre-determined values.

See p-54

SYSTEM LOSSES:

Introduction: The losses that occur throughout radar system reduces the signal to noise ratio at the receiver output. These are of two types depending upon whether or not they can be predicted with any degree of precision beforehand. Various losses are explained below:

1) Plumbing losses:

- There is always some finite loss experienced in transmission lines which connect the output of the transmitter to ant^{ng}.
- At low radar frequencies the transmission line introduces little loss, unless its length is exceptionally long.
- At higher radar frequencies attenuation may not always be small and may have to be taken into account.
- connectors losses are usually small but if connection is poorely made; it can contribute significant attenuation.
- The signal suffers attenuation as it passes through a Duplexer. Greater is isolation reqd for duplexer, larger will be insertion loss. The insertion loss is loss introduced when the component is inserted into transmission line. For typical duplexer, insertion loss is of order of 1dB.

2) **Beam shape loss:** It is added to radar eq^n on account of fact that the maximum gain is employed by the radar equation rather than a gain that changes pulse to pulse. This is simpler albeit less accurate method. It is based on calculating the reduction in signal power & thus not depends on probability of detection. If n be total no. of pulses integrated and n_B be no of pulses received within half power BW θ_B the Beam shape loss is given by

$$\boxed{\text{Beam Shape loss} = \frac{n}{1 + 2\sum_{K=1}^{n-1/2} \exp(-5.55\,k^2/n_B^2)}} \quad ——①$$

The beam shape loss is reduced by the ratio of the square of maximum ant^{na} gain at which pulses were transmitted devided by square of antenna gain at beam center.

- when the ant^{na} scans rapidly enough that gain on transmit is not same as gain on receive & another loss is to be computed called as scanning loss. It is calculated in same way as beam shape loss.

3) **Limiting losses:**

- Limiting in radar can lower the probability of detection.
- Intensity Modulated CRT displays such as the PPI or the B-scope have limited dynamic range and may limit.
- Limiting results in a loss of only a fraction of a decibel for a large no. of pulses integrated, provided limiting ratio (ratio of video limit level to rms noise level) is as large as 2 or 3.

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4) **Collapsing losses:** If the radar were to integrate additional noise samples along with wanted signal to noise pulses, the added noise results in a degradation called the collapsing loss.

- It can occur in displays which collapse the range information such as C-scope which displays elevation vs. azimuth angle.
- A collapsing losses can occur when output of high resolution radar is displayed on device whose resolution is coarser than that inherent to radar.
- A collapsing losses also results if the outputs of two (or more) radar receivers are combined and only one contains signal & other contain noise.
- The collapsing loss in this case is equal to the ratio of the integration loss L_i for $m+n$ pulses to the integration loss for n pulses or,

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

5) **Non ideal equipment:**

→ A loss factor must be introduced due to following factors

(i) A transmitting tubes are not all uniform in quality.

(ii) power is not (usually) uniform over operating band of device.

(iii) variations in receiver noise figure over the ~~overlapp~~ operating band also are to be expected. Thus if the best noise figure over the band is used in radar equation a loss factor has to be introduced to account for its poorer value elsewhere within the band.

- If the receiver is not the exact matched filter for the transmitted waveform a loss in $\frac{S}{N}$ ratio will occur.
- Because of exponential relation between false alarm time & threshold level, a slight change in threshold can cause a significant change in false alarm time. This increase in threshold is equivalent to loss.

6) **operator loss :** The operator must be well trained. However when distracted, tired, overloaded or not properly trained operator performance will decrease.

Based on empirical and experimental results operator efficiency factor is given as

$$\boxed{P_0 = 0.7 (P_d)^2}$$ where

P_d = single scan probability of detection.

7) **Field degradation** Factors which contribute to field degradation are (i) poor tuning (ii) weak tubes (iii) water in transmission lines. (iv) Incorrect mixer crystal current, (v) deterioration of receiver noise figure (vi) poor TR tube recovery (vii) & decay time loose cable connections.

To minimize field degradation radar should be designed with built-in automatic performance-monitoring equipment. Careful observation of performance monitoring instruments & timely preventative maintenance can do much to keep radar performance to design level.

A good estimate of field degradation is difficult to obtain since it cannot be predicted & is depe-

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ndent upon particular radar design. & condition under which it is operating.

8) <u>other loss factors</u>: some other loss factors are :-

(i) loss resulting due to blind speeds in MTI.

(ii) The straddling loss accounts for loss in $\frac{S}{N}$ ratio for target not at centre of ~~target~~ range gate or at centre of filter in a multiple-filter bank processor.

(iii) propagation effects.

* <u>Propagation effects</u>:

<u>Introdn</u>: The effect of the environment on propagation of radar waves can be significant and can make the actual range considerably different from that predicted as if the radar were operated in free space. propagation effects can increase the free range as well as decrease it.

<u>Effects</u>: The major effects of propagation on radar performance are

1) <u>reflections from earth surface</u> which cause the breakup of central elevation pattern into lobes.

2) refraction, or bending of the propagating wave by variations of the atmosphere's index refraction as fn of altitude which usually increases the radar range.

3) propagation in atmospheric ducts which can significantly increase range at low altitudes.

4) Attenuation in the clear atmosphere or in precipitation which usually is negligible at most radar frequencies.

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Propagation effects are not considered as part of system losses but are accounted for seperately by propagation factor usually denoted as F^4 & when appropriate by an attenuation factor $\exp[-2\alpha R]$ where α is attenuation coefficient and R is range.

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Formulae

1) $P_{min} = K(F-1)TB$ = min det. noise power
$= K T_r B$ T_r = receiver noise temp
$= (F-1)T$

2) $R^4 = \frac{P_t A^2 \sigma}{4\pi \lambda^2 P_{min}}$

$A = \frac{\pi D^2}{4}$ D = ant^{na} diameter , $\lambda = \frac{c}{f}$ f = oper^n freq.

3) pulse duration $\tau \geq \frac{1}{B}$

$\therefore \tau = \frac{1}{B}$ for highest resolution.

$\Delta R = \frac{c\tau}{2}$ = range resol^n

4) $r_{unab\,max} = \frac{cT_p}{2}$

5) $PRF = \frac{1}{T_p}$

6) duty cycle $= \frac{\tau}{T_p}$

7) Beam width $= \theta = \frac{70\lambda}{D}$°

8) Combined noise figure
$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots\ldots$

$\frac{1}{4}$

Numerical 4 (see Que asked):

soln

$f = 2.5\ GHz$, $P_t = 25 \times 10^6\ W$ $D = 64\,m$ $\sigma = 1\,m^2$

$F = 1.1$ $BW = 5\,KHz$ $T = 290\,K$

$$R^4 = \frac{P_t A^2 \sigma}{4\pi\lambda^2 P_{min}}$$

$$P_{min} = K(F-1)BT$$

$$= 1.38 \times 10^{-23}(1.1-1) \times 5 \times 10^3$$

$$= \cancel{190 \times 10} \quad x$$

$$= 200100 \times 10^{-23}\ W$$

$$= 2.001 \times 10^{-18}\ W$$

$$= \frac{25 \times 10^6 \times (3215.36)^2 \times 1}{4 \times 3.14 \times (.12)^2 \times 2 \times 10^{-18}}$$

$$= 7.145 \times 10^{14+18}$$

$$= \cancel{7.145 \times 10^{32}}$$

$$R = \underline{1.63 \times 10^{8}\ W}$$

$$A = \frac{\pi}{4} D^2 = \frac{\pi}{4} 64^2$$

$$= \underline{3215.36}\ m^2$$

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{2.5 \times 10^9}$$

$$= 0.12\ m$$

iv) The difference pattern in one plane is formed by taking the sum of two adjacent feeds & substracting this from sum of other two adjacent feeds.

v) The difference pattern in the orthogonal plane is obtained by adding the differences of orthogonal adjacent pairs.

vi) A total of four hybrid junctions generate the sum channel, the azimuth difference channel & the elevation difference channel.

vii) All three mixers operate from single local oscillator in order to maintain the phase relationship betn three channels.

viii) The phase sensitive detectors extract the angle error information, one for azimuth, the other for elevation.

ix) Range information is extracted from the o/p of sum channel after amplitude detection.

Phase Comparasion Monopulse:

→ same introdn.

→ Fig & expln :

i) The angle of arrival θ in one co-ordinate may also be determined by comparing the phase difference betn the signals from two separate antennas. This tracking radar is called phase comparasion monopulse.

ii) Unlike antnas of amplitude comparasion trackers, those used in phase-comparasion systems are not offset from the axis.

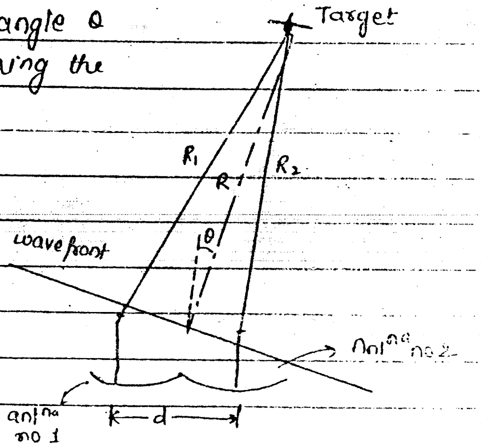
iii) The amplitudes of the target echo signals are essentially the same from each antna beam, but the phases are different.

iv) A tracking radar which operates with phase information is similar to an active interferometer & might be called as interferometer radar.

v) Fig below shows two antnas seperated by distance d.

vi) The distance to the target is R and is assumed large compared with antna seperation d.

vii) The line of sight to the target makes an angle θ to the perpendicular bisector of the line joining the two ant^nas.



viii) The distance of ant^na 1 to the target is

$$R_1 = R + \frac{d}{2}\sin\theta .$$

ix) The distance of ant^na 2 ~~from~~ to target is

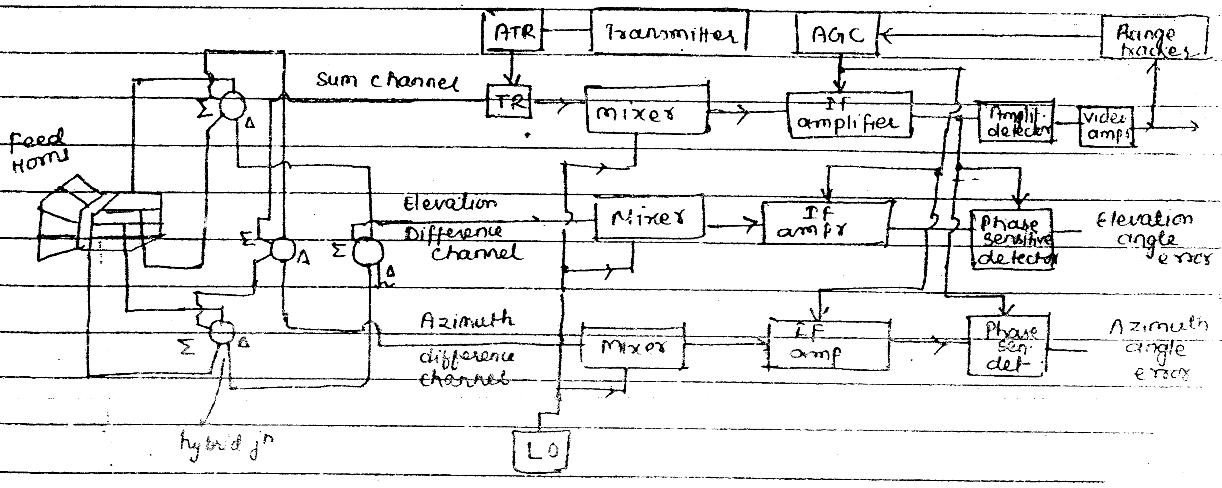
$$R_2 = R - \frac{d}{2}\sin\theta .$$

x) The phase diff betn the echo signals in two ant^nas is approximately

$$\Delta\phi = \frac{2\pi}{\lambda} d\sin\theta .$$

For small angles where $\sin\theta \approx \theta$, the phase difference is a linear f^n of the angular error & may be used to position ant^na via a servo control loop.

Fig(1) for Ampl. comp. monopulse with 2 co-ordinate :



Que: Describe equipments and techniques used in monopulse method or target ~~targ~~ tracking.

Que: Describe the method of lobe switching as used to track a target after it has been aquired. In what ways this lobe ~~as~~ Switching an improvement over merely pointing an'na accurately at the target.

UNIT: TWO (CW AND FM: CW RADAR)

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* **The doppler effect** It is well known fact in field of optics that if either the source of oscillation or the observer of oscillation is in motion, an apparent shift in frequency will result. This is called the doppler effect and is the basis of CW radar.

→ If R is the distance from radar to target the total numbers of wavelengths λ contained in the two way path between the radar and target $= \frac{2R}{\lambda}$

→ Since one wavelength corresponds to an angular excursion of 2π radians, the total angular excursion of made by the electromagnetic wave during its transit to & from the target is $4\pi R/\lambda$ radians i'e

$$\boxed{\phi = \frac{4\pi R}{\lambda}}$$

→ **The doppler frequency:** If the target is in motion, R and the phase ϕ are continously changing. A change in ϕ with respect to time is equal to frequency this is called doppler frequency and it is given by

$$\omega_d = 2\pi f_d = \frac{d\phi}{dt}$$

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

$$\boxed{\omega_d = \frac{4\pi v_r}{\lambda}}$$ where

v_r - relative velocity of target wrt radar

→ **The doppler frequency shift:** The doppler frequency shift is given by

$$f_d = \frac{2v_r}{\lambda} = \frac{2v_r f_0}{c} \quad (\text{as } \lambda = \frac{c}{f_0})$$

here, f_0 = transmitted frequency, $c = 3\times10^8$ m/s.

→ Also if f_d is in H_z and V_r in knots and λ is in meters, then

$$\boxed{f_d = \frac{1.03 V_r}{\lambda}}$$

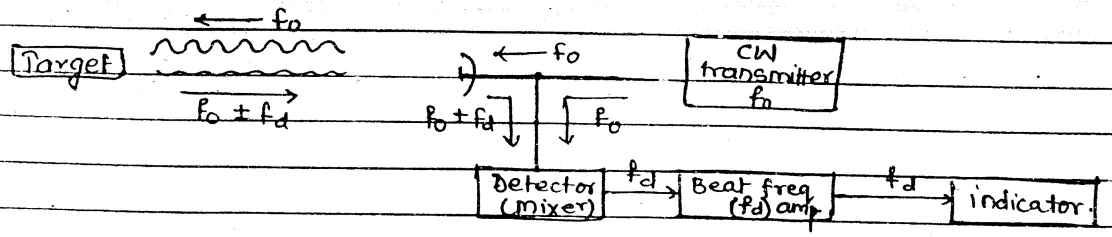
→ The relative velocity may be written as $V_r = v\cos\theta$ where v is the target trajectory & line joining radar and target.
Thus when $\theta = 0$, the doppler freq f_d is maximum.
when $\theta = 90$, the doppler freq f_d is minimum.

* CONTINOUS WAVE (CW Radar) :

Introduction: The continous wave radar serves as a means for better understanding the nature and use of the doppler information contained in the echo signal. It provides a measurement of relative velocity which may be used to distinguish moving targets from stationary objects or clutter. Doppler effect is basis of CW radar.

Principle: Introduce doppler effect

A simple CW radar block diagram: A simple CW radar block diagram is shown below & explained in points below:



Operation : ① The transmitter generates a continous (unmodulated) oscillation of frequency f_0, which is radiated by antenna.

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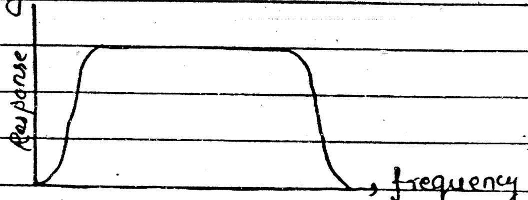
2> A portion of radiated energy is intercepted by the target and is scattered, some of it in dir^n of radar where it is collected by the receiving antenna.

3> If the target has velocity v_r relative to radar, the received signal will be shifted in frequency from transmitted frequency f_0 by an amount $\pm f_d$ as given by $f_d = \frac{2v_r}{\lambda}$.

4> The plus sign with f_d indicates that distance between target and radar is decreasing & negative sign indicates that it is ~~de~~increasing.

5> The received echo signal at a frequency $f_0 \pm f_d$ enters the radar via antenna & heterodyned in detector with portion of transmitted signal f_0 to produced doppler beat freq. f_d, whose sign is lost in process.

6> The f^n of doppler or beat freq amp: It eliminates echoes from stationary targets & amplify the doppler echo signal to a level where it can operate an indicating device.
It has a frequency response as shown ~~below~~ here.



7> The indicator might be a pair of earphones or a frequency knowledge.

* **Isolation between transmitter & receiver:** The necessary isolation bet^n transmitted & received signals is achieved by separation in frequency as a result of doppler effect in simple cw radar. In practice, transmitter leakage which is not always undesirable ~~is not~~ can't be eliminated completely. There are two practical effects which limit the amount of transmitter leakage

power which can be tolerated at receiver.

1) max. power which receiver can withstand without any demage or sensitivity reduced.

2) amount of transmitter noise due to hum, stray pickups etc.

Additional isolation is required betn transmitter and receiver if sensitivity is not to be degraded either by burnout or excessive noise. The imp. points regarding this are explained below :-

1) The amount of isolation required depends on transmitter power and accompanying transmitter noise as well as ruggedness & sensitivity of the receiver.

2) The amount of isolation needed in long-range CW radar is more often determined by the noise that accompanies the transmitter leakage signal rather than any demage caused by high power.

3) The receiver of pulsed radar is isolated and protected from demaging effects of transmitted pulse by ~~radar~~ duplexer which short ckts receiver i/p during transmission period. Turning off the receiver in CW radar during transmission is not possible since transmitter is operated continously. Isolation betn transmitter & receiver might be obtained with single antenna by using hybrid junction, circulator. etc.

4) The largest isolations are obtained with two antennas - one for transmission and other for reception - physically seperated from one another. The more directive the antenna beam & the greater is spacing betn the antenaas, the greater will be isolation.

5) Additional isolation can be obtained by properly introducing a controlled sample of transmitted signal directly into the receiver. The phase & amplitude of this "buck-off" signal are adjusted to cancel the portion of transmitter signal that leaks into the receiver.

6) The transmitter signal is never a pure CW waveform. Minute variations in amplitude (AM) & phase (FM) can result in sideband components that fall within

flicker noise
→ occurs in s/c devices
→ $\propto 1/f^{\alpha}$ $\alpha \approx 1$

Bikesh

doppler frequency band. These can generate false targets or mask the desired signals. Thus both AM & FM modulations can result in undesired side-bands. The normal antna isolation plus feedthrough usually reduces the AM components below receiver noise in moderate power radars.

7) The transmitter noise that enters the radar receiver via backscatter from clutter is called transmitted clutter. It can mask desired targets or cause spurious responses.

8) Noise free operations also requires well filtered beam power supplies and dc heater supplies.

* Intermediate-frequency receiver:

Introdn: The receiver of simple CW radar is analogous to a superheterodyne receiver. Such receivers are called homodyne or superheterodyne receivers with zero IF.

At lower range of frequencies where the doppler frequencies are usually found, the detector of CW receiver can introduce a considerable amount of flicker noise resulting in reduced receiver sensitivity. For short range, low power applications this may be neglected but for maximum efficiency, redn in sensitivity caused by simple doppler receiver with zero IF can't be tolerated. Thus effects of flicker noise are overcome in normal superheterodyne receiver by using IF high enough to render the flicker noise small compared with simple receiver.

Block diagram: Fig below shows block diagram of the CW radar whose receiver operates with non-zero IF & explained below:—

1) Seperate antnas are used for transmission and reception.

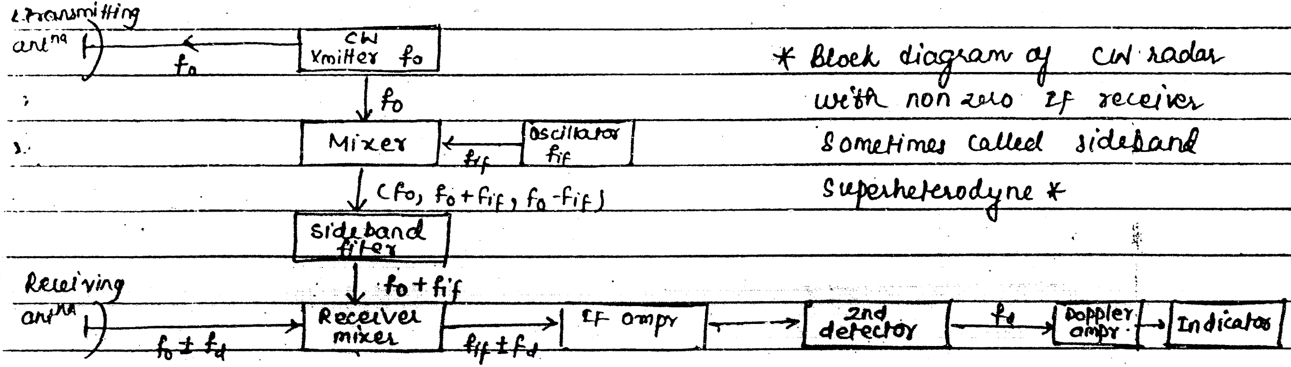
2) The local oscillator (or reference signal) is derived in the receiver from a portion of transmitted signal mixed with a locally generated signal of frequency equal to that of receiver IF.

3) Thus, o/p of mixer consists of two sidebands on either side of carrier plus higher harmonics.

4) The o/p of mixer is passed through a narrowband filter which selects one of the sidebands as reference signal.

5) The improvement in receiver sensitivity with an IF superheterodyne might be as much as 30 dB over the simple receiver.

6) The indicator might be pair of earphones or frequency knowledge.



* Block diagram of CW radar with non zero IF receiver sometimes called sideband superheterodyne *

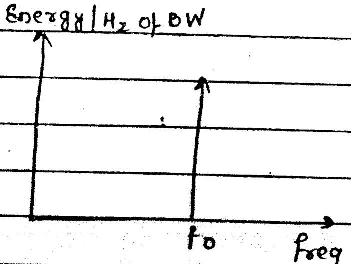
* **Receiver Bandwidth**: One of the requirements of doppler-frequency amplifier in CW radar is that it must be wide enough to pass expected range of doppler frequencies. consequently use of wideband amplifier will result in 1) increase in noise.
2) lowering of ~~receiver~~ receiver sensitivity

Bikash

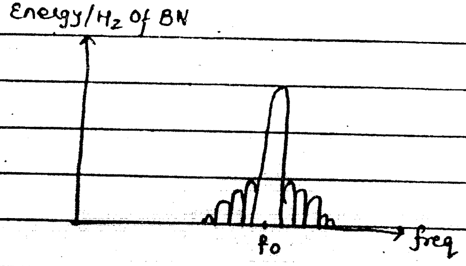
- If the frequency of doppler shifted echo signal were known beforehand a narrowband filter-wide enough to reduce excess noise without eliminating ~~eliminating~~ a significant amount of signal energy might be used.

→ Several factors tend to spread the CW signal energy over a finite frequency band. These must be known if bandwidth reqd. for the narrowband doppler filter is to be obtained.

- If the received waveform were a sinewave of infinite duration, its frequency spectrum would be delta fn (Fig a) & receiver BW would be infinite small. But these can't occur in nature.



((Fig(a))



(fig(b))

- The more normal situation is an echo signal which is sinewave of finite rather than infinite duration. The freq spectrum of finite duration sinewave is shown in fig(b).
- spectrum broadening also may result due to fluctuations in cross-section, target accelerations etc. The fluctuation widen the spectrum by modulating the echo signal.
- If the target's relative velocity is not constant, a further widening of the received signal spectrum can occur. If a_r is acceleration of the target wrt radar the signal will occupie a bandwidth

$$\boxed{\Delta f_d = \left(\frac{2a_r}{\lambda}\right)^{1/2}}$$

→ when the doppler-shifted echo signal is k n to lie somewhere with in a relatively wide band of freq ies, a bank of narroo-band filters spaced throughout the frec cy range permits a measurement of frequency & improves t signal to noise ratio. the fig is shown below:

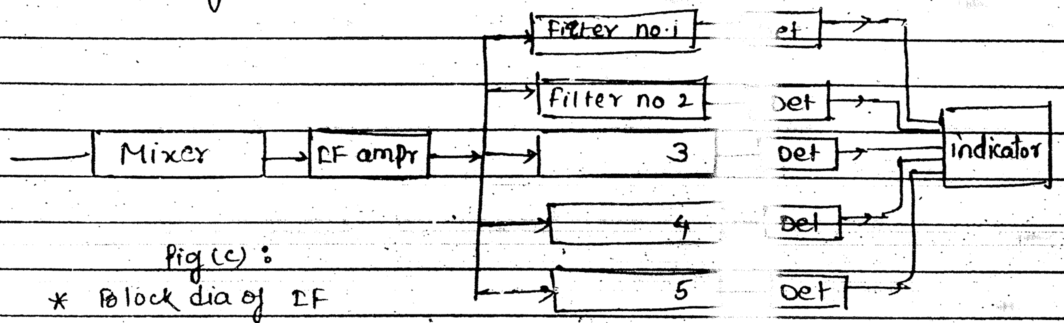
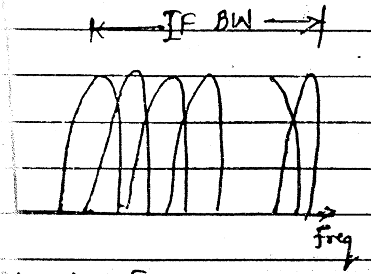


Fig (c) :
* Block dia of IF doppler filter bank *



ig(d) : Freq. response *

✓a) The BW of each individual filter is wide enough to accept signal energy but not so wide as to introduce more noise than need be.

✓b) The centre frequencies of the filters are staggered to cover entire range of doppler frequencies.

c) More the filters used to cover the b , the less will be the maximum loss experienced but greate probability of false alarm.

* ✓d) A bank of overlapping doppler filters increase complexity of receiver. ~~of the receiver~~.

e) After detecting & recognizing the signal, t filter may be programmed to continue its search in frequen f additional signals.

* Sign of radial velocity:

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In some cases it is interesting to know whether target is approaching or receding. This might be determined with seperate filters located on either side of intermediate frequency. If the echo signal frequency lies below the carrier, the target is receding if echo freq is greater than the carrier, the target is approaching. [fig a]

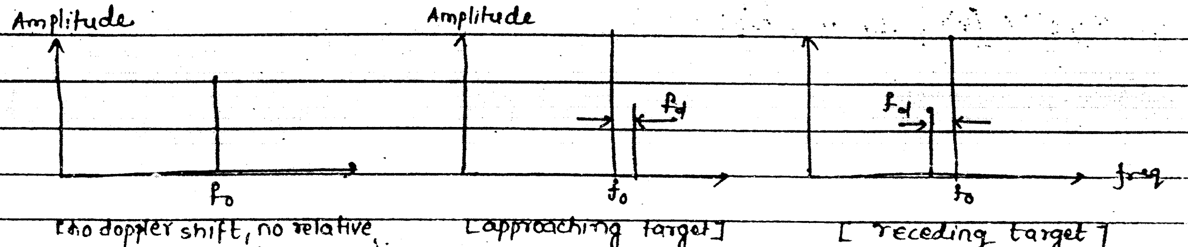
consider if the transmitter signal is

$$E_t = E_0 \cos \omega_0 t \quad \text{— ①}$$

the echo signal from moving target will be

$$E_r = k_1 E_0 \cos[(\omega_0 + \omega_d)t + \phi] \quad \text{where} \quad \text{— ②}$$

E_0 = amplitude of transmitter signal.
k_1 = a constant determined from the radar eq^n.
ω_0 = angular freq of transmitter, rad/s.
ω_d = doppler angular frequency shift
ϕ = constant phase shift.



[no doppler shift, no relative motion] [approaching target] [receding target]

Fig(a)

A method to determine the sign of doppler freq is illustrated in fig(b) in which received signal is splitted into two channels. In one channel signal is processed simply as in CW radar while the same in other channel with phaseshift of 90°. Thus o/p of channel A & B ~~are~~ mixers are.

$$E_A = k_2 E_0 \cos(\pm\omega_d t + \phi) \quad \text{— ③}$$

$$E_B = k_2 E_0 \cos(\pm\omega_d t + \phi + \frac{\pi}{2}) \quad \text{— ④}$$

Thus if target is approaching (positive doppler) the o/p of two channels are,

$E_A(+) = K_2 E_0 \cos(\omega_d t + \phi)$, $E_B(+) = K_2 E_0 \cos(\omega_d t + \phi + \frac{\pi}{2})$

and, if targets are receding (negative doppler) ;

$E_A(-) = K_2 E_0 \cos(\omega_d t - \phi)$, $E_B(-) = K_2 E_0 \cos(\omega_d t - \phi - \pi/2)$

The sign of ω_d & dir^n of the target's motion may be determined according to whether o/p of channel B lags or leads to o/p of channel A.

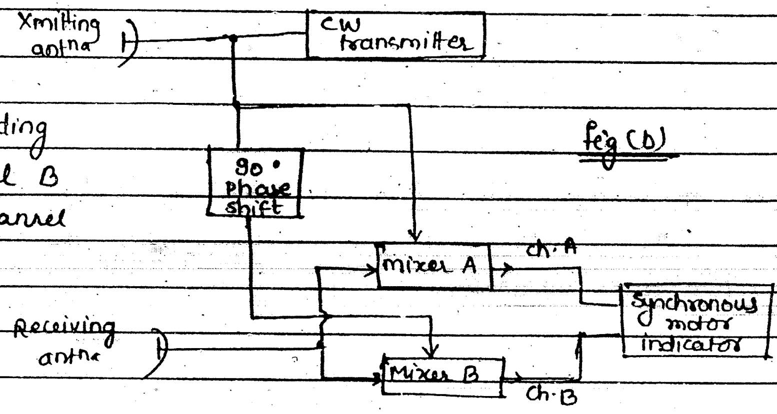


fig (b)

*** The doppler frequency shift :** The expression for the doppler frequency shift given by $f_d = 2 v_r f_0$ or $1.03 v_r$ is approximate, but its ~~cos~~ valid for most ^{c}radar ^{1}applications. The correct expression for freq f^* from a target moving with relative velocity v when transmitted freq is f is given by

$$\boxed{f^* = f \frac{(1+v/c)}{(1-v/c)}}$$

c = velocity of propagation

if $v \ll c$ $f^* = f$. The phase shift associated with return signal is $\left(\frac{4\pi f R_0}{c}\right) / (1 - v/c)$ where R_0 is range at $t=0$.

*** Applications of CW radar:** It can be used :-

1) For measurement of the relative velocity of moving target, as in the police speed monitor.

2) CW radar has been suggested for control of traffic lights, regulation of toll booths, vehicle counting.

Bikesh

3) For railways CW radar can be used as a speedometer to replace the conventional axle-driven tachometer.

4) As a detection device, to give track maintenance personnel advance warning of approaching trains.

5) For monitoring the docking speed of large ships.

6) For intruder alarms & for measurement of the velocity of missiles, ammunition and baseballs.

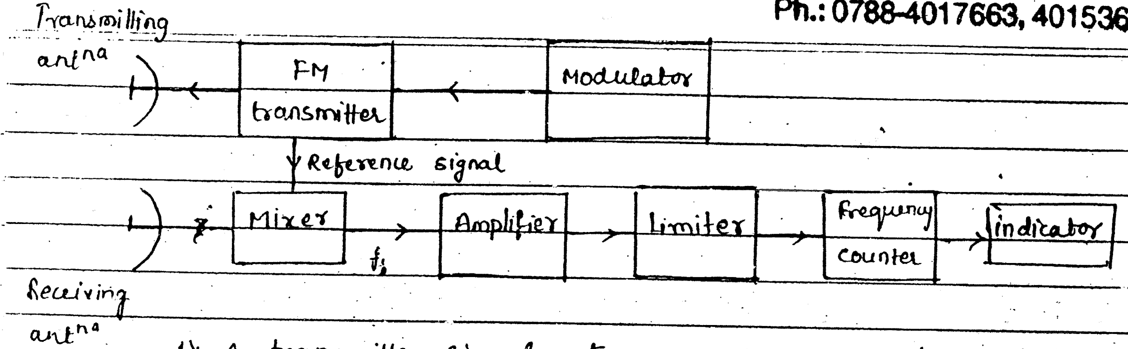
Important : The principal advantage of CW doppler radar over other (non radar) methods of measuring speed is that there is no physical contact with the object ~~which~~ whose speed is being measured.

✗ FREQUENCY MODULATED CW Radar :

Limitation of simple CW Radar (Introdⁿ to ~~RW~~ FMCW Radar) : The inability of the simple CW radar to measure range is related to the relatively narrow spectrum (BW) of its transmitted waveform. Some sort of timing must be marked to CW radar of carrier if range is to be measured. The spectrum of a CW transmission can be broadened by application of modulation, either amplitude, frequency or phase.

A widely used technique to broaden the spectrum of CW radar is to frequency-modulate the carrier. The timing mark is changing frequency. Greater is the transmitter frequency deviation in a given time interval, the more accurate the measurement of the transit time and the greater will be transmitted spectrum. Thus, " A CW radar in which carrier is frequency modulated to broaden its spectrum for range calculation is called FMCW radar".

Block diagram : A block diagram illustrating the principle of FMCW radar is shown below & explained in points:-



1) A transmitter signal acts as a reference signal reqd to produce the beat frequency. It is introduced directly into the receiver through cable or other direct connection.

2) The isolation between transmitting & receiving antnas is made sufficiently large so as to reduce to a negligible level the transmitter leakage signal which arrives at receiver via coupling betn antnas.

3) The beat frequency is amplified & limited to remove any amplitude fluctuations.

4) The frequency of the amplitude-limited beat note is measured with a cycle counting frequency counter caliberated in distance.

5) The indicator might be pair of earphones or a frequency ~~known~~ meter.

6) In above case, target was assumed to be stationary. If target is not stationary a doppler frequency shift will be superimposed on FM range beat note & an erroneous range measurement results.

7) The doppler frequency shift causes the frequency-time plot of echo signal to be shifted upor down as shown below in fig(a).

8) The beat frequency Vs time due to shift in freq of received signal by doppler

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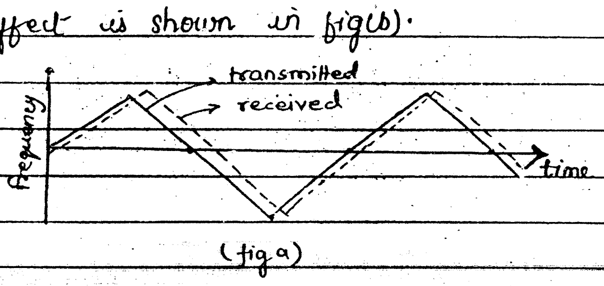
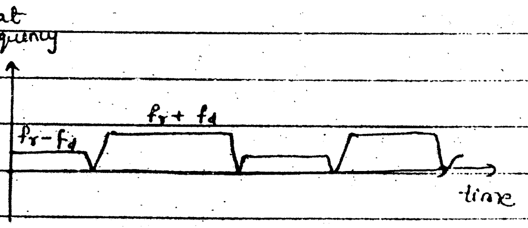
effect is shown in fig(b).



(fig a)



9) beat frequency on increasing & decreasing portions will be

$$f_b(up) = f_r - f_d$$
$$f_b(down) = f_r + f_d$$

10) The range frequency f_r may be extracted by measuring the average beat frequency ie $f_r = \frac{f_b(up) + f_b(down)}{2}$.

11) when more than one target is present the mixer o/p will contain more than one difference frequency. To measure the individual frequencies, they must be seperated from one another which can be obtained with bank of narrowband filters.

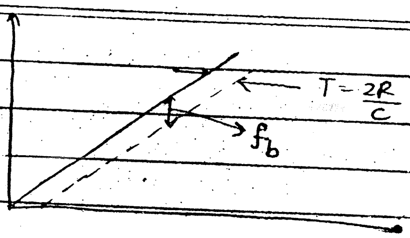
* **Beat frequency** (To write only if asked seperately) / **Range & doppler measurement**

Assume that in FMCW radar transmitter frequency increases linearly with time as shown in fig. If there is a reflecting object at a distance R an echo signal will return after time $T = \frac{2R}{c}$. The dashed line repesents the echo signal. If the echo signal is heterodyned with portion of transmitter signal in a non-linear element such as diode a beat note f_b is produced. If there is no doppler frequency shift the beat note is measure of targets range ~~to~~ where and $f_b = f_r$ where f_r is beat frequency only due to targets range. If rate of change of carrier frequency is $\dot{f}_0$ then beat frequency is

$$f_r = \dot{f}_0 T = \frac{2R}{c} \dot{f}_0$$

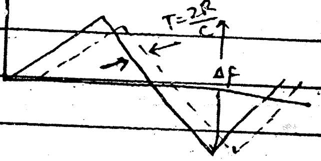
6.1.05

In practical CW radar frequency may change are not in one-dir^n continously. If we consider traingular wave as shown & if frequency is modulated at a rate fm over range Δf the beat frequency is



$$\boxed{f_r = \frac{2R}{c} \times 2f_m \times \Delta f} \Rightarrow \boxed{f_r = \frac{4Rf_m\Delta f}{c}}$$

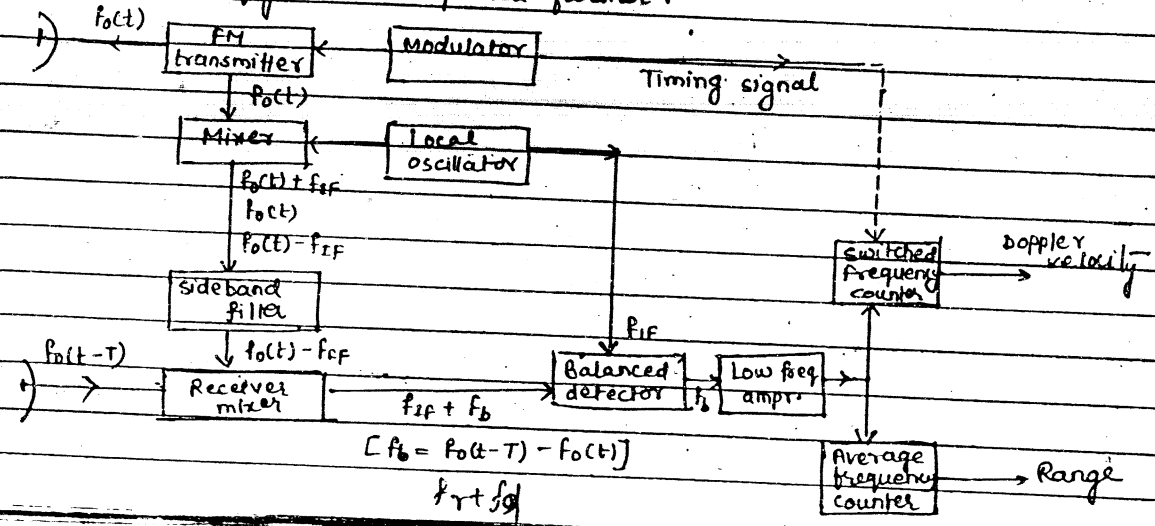
Thus measurement of beat freq determines R.



* FM-CW altimeter :

Introduction : The FM-CW radar principle is used in the aircraft radio altimeter to measure height above earth surface. The altimeter can employ a simple homodyne receiver but for better sensitivity & stability the superheterodyne is to be prefered whenever its more complex constr^n can be tolerated.

Block diagram of FM-CW radar using sideband superheterodyne receiver : A block diagram of the FM-CW radar with a sideband superheterodyne receiver as shown in fig below & explained further :



$[f_b = f_0(t-T) - f_0(t)]$

$f_r + f_d$

Bikesh

Explaination: 1) As shown in fig a portion of frequency moduiated transmitted signal is applied to a mixer along with oscillator signal.

2) The local-oscillator frequency f_{IF} should be same as the intermediate frequency used in the receiver. (whereas in conventional super heterodyne the LO frequency is of same order of magnitude as the RF signals).

3) The o/p of the mixer consists of varying transmitter frequency $f_o(t)$ plus two sideband frequencies one on either side of $f_o(t)$ and seperated from $f_o(t)$ by local oscillator frequency f_{IF}.

4) The filter selects the lower sideband $f_o(t) - f_{IF}$ and rejects the carrier and the upper sideband.

5) The sideband filter must have a sufficient bandwidth to pass the modulation, but not the carrier or other sideband. The filtered sideband serves as funcⁿ of the local oscillator.

6) when an echo signal is present, the o/p of receiver mixer is an IF signal of frequency $f_{IF}+f_b$ where f_b is composed of the range frequency f_r and the doppler velocity frequency f_d as shown in figure.

7) The IF signal is then amplified and applied to balanced detector along with the local oscillator signal signal f_{IF}.

8) The o/p of detector contains the beat frequency which is amplified to a level where it can actuate the frequency-measuring ckts.

9) The o/p of low frequency amplifier is divided into two channels: one feeds an

$$\Rightarrow R = \frac{c\,\Delta\phi}{4\pi f_0} = \frac{\lambda}{4\pi}\Delta\phi \quad \left[\text{as } \lambda = \frac{c}{f_0}\right] \text{ — ①}$$

however measurement of $\Delta\phi$ is unambigous only if $\Delta\phi \leq 2\pi$,
∴ subst $\Delta\phi = 2\pi$

$$R = \frac{\lambda}{4\pi}\,2\pi$$

$$\Rightarrow \boxed{R_{amb} = \frac{\lambda}{2}}$$

At radar frequencies this unambigous range is too small.
The region of unambiguous range ~~be~~ may be extended by utilizing two seperate cw signals differing slightly in frequency.

Now consider that the transmitted waveform is consisting of two continous sine waves of frequency f_1 & f_2 & seperated by Δf. Their voltage waveforms can be written as

$$v_{1T} = \sin(2\pi f_1 t + \phi_1)$$
$$v_{2T} = \sin(2\pi f_2 t + \phi_2)$$

where ϕ_1 & ϕ_2 are phase angles.
The form of doppler shifted signals at these frequencies may be given by

$$V_{1R} = \sin\left[2\pi(f_1 \pm f_{d_1})t - \frac{4\pi f_1 R_0}{c} + \phi_1\right]$$

$$V_{2R} = \sin\left[2\pi(f_2 \pm f_{d_2})t - \frac{4\pi f_2 R_0}{c} + \phi_2\right]$$

where

R_0 = range to target at particular time $t = t_0$.
f_{d1} = doppler freq shift associated with freq f_1.
f_{d_2} = —— " —— f_2.

Bikesh

Now since two RF frequencies f_1 & f_2 are almost same;

$\therefore \; f_{d_1} = f_{d_2} = f_d$

The receiver separates the two components of echo signal & extracts the two doppler frequency components given by

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

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

The phase diff betn these components is

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

$$\therefore \boxed{R_0 = \frac{c\,\Delta\phi}{4\pi\,\Delta f}} \quad \text{———} \; ②$$

Thus ① & ② are same with Δf substituted in place of f_0.

Now put $\Delta\phi = 2\pi$

$$\boxed{R_{\substack{unamb \\ max}} = \frac{c}{2\Delta f}} \quad \text{or} \quad \boxed{\Delta f = \frac{c}{2R_{unamb}}}$$

Thus Δf must be less than $\frac{c}{2R_{unamb}}$.

The measurement of range by measuring phase difference betn seperated frequencies is ~~equal to~~ analogous to measurement of angle by measuring phase difference betn widely spaced antnas.

The range can be thus measured in multiple freq radars by measuring phase difference betn seperated frequencies.

Bikesh

Applications

1) used in surveying.

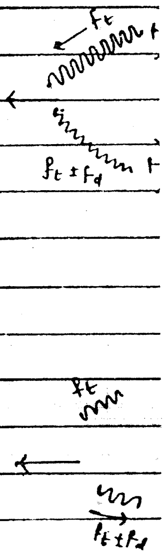
2) In range instrumentation radar for measuring distance to missile, satellites.

3) in satellite navigation systems.

4) For detecting presence of an obstacle in path of moving automobile by measuring the distance, doppler velocity & sign of doppler.

Introduct

Operation



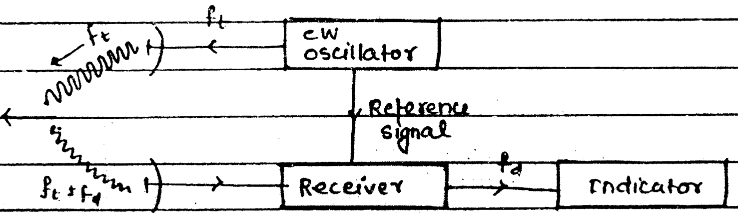
(iv) Th
dc

UNIT-3

MTI Radars

Introduction: A pulse radar which utilizes the doppler frequency shift for discriminating moving targets from fixed one appearing as clutter (any unwanted radar echo) is known as MTI Radars i.e moving target indication radar. It usually operates with ambigous doppler measurement but with unambigous range measurements. The opposite is generally the case of a pulse doppler radar which also discriminates moving targets from clutter by doppler frequency shift measurements. MTI is necessity in high quality air-surveillance radars which may operate in presence of clutter.

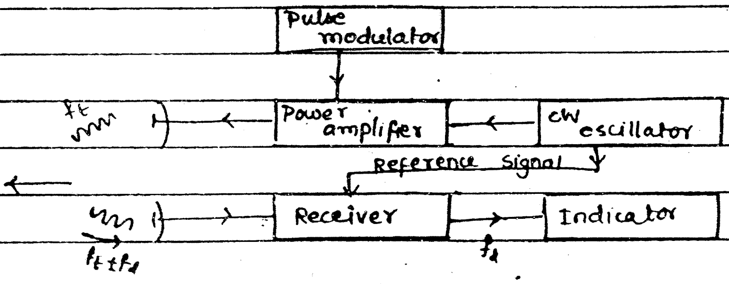
Operation: The fig illustrating operation of MTI radars is shown below & explained further:



fig(a): CW radar

(i) As shown in fig@ a simple CW radar consists of a transmitter, receiver, indicator & antenas.

(ii) It may be converted in to a pulse radar by providing a power-amplifier and a modulator (fig b).



fig(b): pulse radar using doppler informatⁿ

(iii) The chief difference betⁿ ~~bo~~ them is that a small portion of CW oscillator power that generates the transmitted pulses is diverted to the receiver in order to take place of the local oscillator.

(iv) This CW signal acts as a coherent reference signal reqd. for detecting the doppler shift. By term coherent it meant that phase of the transmitted role in both the receiver and the transmitter.

vi) Although the phase of the stalo influences the phase of transmitted signal but get compensated on reception because the stalo that generates the transmitted signal also acts as local oscillator in the receiver.

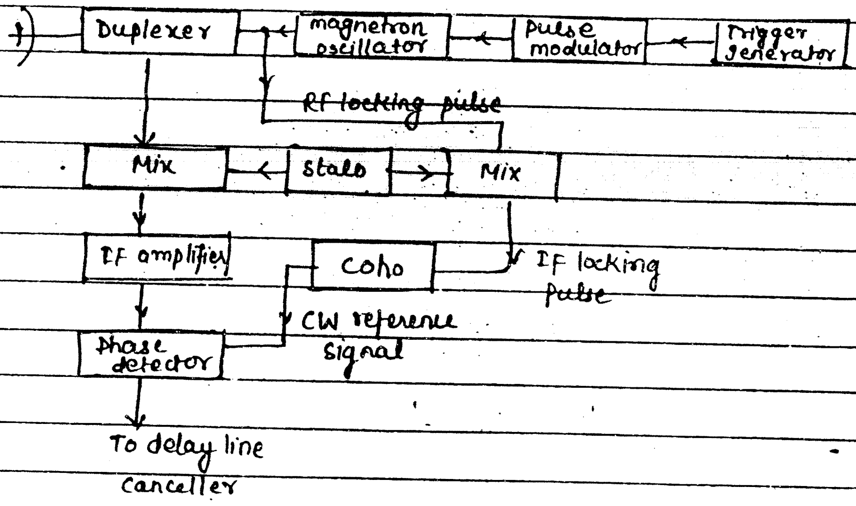
vii) The reference signal from coho and the IF echo signal are both fed into the mixer called phase detector whose o/p is proportional to phase differences between two input signals.

viii) Examples of power amp^rs used are triode, tetrode, klystron etc each of which has certain adv & dis adv.

* MTI radars using power-oscillator transmitter:

→ Introduce MTI radars.

Block diagram



~~i), ii), iii)~~

i) Same
ii) same
iii) iv) of power-ampr. (remove also)

iv) A portion of transmitted signal is mixed with stalo o/p to produce an IF beat signal whose phase is directly related, to that of transmitter.

v) This IF pulse is applied to coho & causes the phase of coho CW oscillation to 'lock' in step with phase of IF reference pulse.

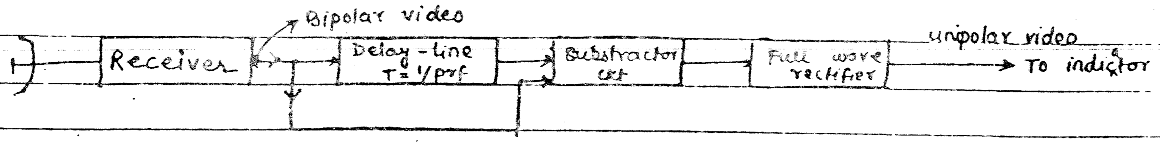
vi) The phase of coho is then related to phase of transmitted pulse and may be used as reference signal for echoes received from that particular transmitted pulse.

vii) same

★ DELAY-LINE CANCELERS:

Introdn: The superposition of many sweeps is not appropriate for display on the PPI unlike A-scope. One method commonly employed to extract doppler information in a form suitable for display on PPI scope is with a delay line canceler. The delay line canceller acts as a filter to eliminate the dc components of fixed targets & to pass ac components of moving targets.

Block diagram: The block diag of simple delay line canceller is shown below and explained further



working

1) As shown the video portion of the receiver is divided into two channels.
2) one part of video portion is then delayed by one pulse repetition period ($\approx \frac{1}{prf}$).

3) Then both the delayed & undelayed portions from two channels are applied to substractor ckt.
4) The fixed targets with unchanging amplitudes from pulse to pulse are Canceled on substraction.
5) However, the amplitudes of the moving-target echoes are not constant from pulse to pulse and substraction results in uncanceled residue.
6) The o/p of the substraction ckt is bipolar video just as was the input. It must be converted to unipotential voltages by full wave rectifier for display on PPI.

Other features 1) The simple delay line canceler shown is example of time domain filter & is thus called time domain dLC.
2) The delay line must introduce a time delay equal to pulse repetition interval whose typical value is several ms which is impractical to achieve.
3) The ~~quo~~ capability of this device thus depends on quality of medium used as delay line.

Advantage : A single network operates at all ranges & does not require a seperate filter for each range resolution cell.

Disad – pt 2.

☐ FILTER CHARACTERISTICS OF DLC : The delay line canceller acts as a filter which rejects dc components of clutter. Because of its periodic nature, the filter also rejects energy in the vicinity of prf and its harmonics.

Let video signal received from particular target at range R_0 is

$$v_1 = k\sin(2\pi f_d t - \phi_0) \quad \text{——} ①$$

The delayed signal is

$$v_2 = k\sin[2\pi f_d (t-T) - \phi_0] \quad \text{——} ②$$

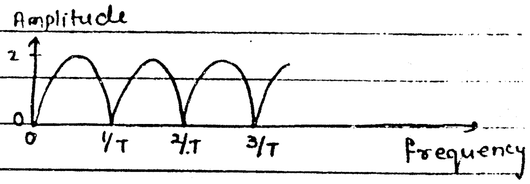
where $T = \frac{1}{prf}$ ~~= pr~~ = pulse repetition period.

Thus the o/p of substractor is

$$\boxed{V = v_1 - v_2 = 2k\sin \pi f_d T \cos\left[2\pi f_d (t - T/2) - \phi_0\right]} \quad \text{——} ③$$

Thus o/p from canceler has amplitude $2k\sin \pi f_d T$ ~~or~~ & is cosine wave at doppler freq f_d.

The frequency response of single dLC is shown here.



* Blind speeds

Introdn: The blind speeds are one of limitations of ~~of~~ pulse MTI radar which do not occur with cw radar. They are present in pulse radar because doppler is measured by discrete samples at prf rather than continously. It can be defined as "Relative target velocities which results in zero MTI response are called blind speeds".

Explaination As response of single delay line canceller is given by ③ above, when ever argument $\pi f_d T$ in amplitude factor of ③ will be $0, \pi, 2\pi \ldots$ the response will be zero ie when

$$f_d = \frac{n}{T} = nf_p \qquad n = 0, 1, 2, \ldots$$
$$f_p = prf$$

The dLC not only eliminates dc components caused by clutter (n=0) but it also rejects any moving target whose doppler frequency happens to ant^na pattern is

$$S_a(t) = k\exp\left(-\frac{2.776\,t^2}{t_0^2}\right) \qquad k = \text{const} \quad \text{——} ②$$

Thus angular frequency spectrum of ② is

$$S_a(f) = k\int_{-\infty}^{\infty} \exp\left(\frac{-2.776\,t^2}{t_0^2}\right)\exp(-j2\pi f t)\,dt$$

$$= k_1 \exp\left[-\frac{\pi^2 f^2 t_0^2}{2.776}\right] \qquad k_1 = \text{const} \quad \text{——} ③$$

Since ③ is of gaussian form, the exponent is of form $\frac{f^2}{2\sigma_f^2}$ where σ_f = standard deviation. Therefore

$$\cancel{\sigma_f}\frac{f^2}{2\sigma_f^2} = \frac{\pi^2 \cancel{f^2} t_0^2}{2.776}$$

$$\sigma_f^2 = \frac{2.776\,\cancel{\pi^2 t_0^2}}{2\pi^2 t_0^2}$$

$$\Rightarrow \sigma_f^2 = \frac{1.388}{\pi^2 t_0^2} \Rightarrow \boxed{\sigma_f = \frac{1.178}{\pi t_0}}$$

Thus power spectrum due to ant^na scanning is described by standard eq^n

$$\sigma_s = \frac{\sigma_f}{\sqrt{2}} = \frac{1.178}{\sqrt{2}\pi t_0} \Rightarrow \boxed{\sigma_s = \frac{1}{3.77\,t_0}}$$

Thus, since

$$I_{1s} = \frac{f_p^2}{2\pi^2\sigma_c^2} = \frac{f_p^2}{2\pi^2 \cdot \frac{1}{(3.77t_0)^2}} = \cancel{n_8}\ \frac{t_0^2 f_p^2}{1.388} \qquad (\text{where } \sigma_s = \sigma_c)$$

$$\text{or} \quad \boxed{I_{1s} = \frac{n_8^2}{1.388}} \qquad (\text{Single canceler})$$

3) Antenna scanning modulation: As antenna scans by a target, it observes the target for finite time equal to

$$t_0 - \frac{n_B}{f_p} = \frac{\theta_B}{\dot{\theta}_s} \quad \text{where}$$

n_B = no. of hits received. θ_B' = ant^{na} beamwidth

f_p = pulse repetition frequency. $\dot{\theta}_s$ - ant^{na} scanning rate.

Thus even if the clutter were perfectly stationary there will still be a finite width to the clutter spectrum because of finite time on target. If the clutter ~~time~~ spectrum is too wide because the observation time is too short, it will affect the improvement factor. This limitation is called scanning fluctuation or scanning modulation.

Cal^n of limitation to improvement factor: considering that the ant^{na} main beam pattern is approximated by Gaussian shape the spectrum will also be gaussian. The voltage waveform of the received signal is modulated

* by square of ant^{na} electric field strength pattern which is equal to ant^{na} power pattern $G(\theta)$ described by

$$G(\theta) = G_0 \exp\left(-\frac{2.776\theta^2}{\theta_B^2}\right) \qquad ①$$

Dividing the N^r & D^r of exp by $\dot{\theta}_s$ & letting $\frac{\theta}{\dot{\theta}_s} = t$ the time variable and $\frac{\theta_B}{\dot{\theta}_s} = t_0$ the time on target, the modulation of received signal due

If σ_c = rms clutter frequency Hz
& σ_v = rms velocity spread m/s

if sufficient care is not taken in design, constr^n & maintenance.

If we consider the effect of phase variations in an oscillator. The limitation on improvement factor due to oscillator instability is $I = \frac{1}{(\Delta\phi)^2}$ where

$\Delta\phi$ = change in oscillator phase bet^n two pulses.

2) Internal fluctuation of clutter: There are many types of clutter that cannot be considered as stationary. Echoes from trees, vegetation, sea, rain etc fluctuate with time and these fluctuations can limit the performance of MTI radar.

For purpose of analysis, most fluctuating target can be considered as model consisting of many independent scatterers. ~~scattered~~ The echo at the receiver is vector sum of the echo signals received from each of individual scatterers. If the individual scatters remains fixed from pulse to pulse the resultant echo signal will as remain fixed] But phase & amplitude of resultant echo signal will differ pulse to pulse if scatters relative to radar result in different phase relationships at radar receiver.

It can be shown that general expression for improvement factor for N-pulse canceler with $N_L = N-1$ delay lines is

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

*. Proof: The proof is given below:

The power spectra of clutter signals is experimentally measured as

$$W(f) = |g(f)|^2 = |g_0|^2 e^{-a(f/f_0)^2} \quad \text{where} \qquad ①$$

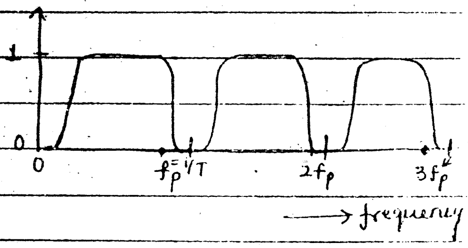
$W(f)$ = clutter power spectrum as f^n of frequency

$g(f)$ = Fourier transform of i/p waveform (clutter echo)

f_0 = radar carrier frequency a = parameter dependent on clutter.

9) o/p from each of range channels must be properly combined for display on PPI or A-scope.

Features 1) The width of range gates depends on range accuracy desired.
2) Range resolution is established by gating.
3) collapsing loss does not take place since noise from other range intervals is excluded.
4) Its frequency response is shown below:



Disadvantage 1) more complex
2) costly.

Advantages 1) avoids collapsing losses.
2) improved sensitivity
3) No loss in range information.

*** Limitations of MTI performance:** The improvement in signal to clutter ratio of an MTI is affected by factors other than the design of doppler signal processor. Following are the factors that can ~~detract~~ limit the performance of MTI radar:-

1) Equipment instability: The stability of the equipment in MTI radar must be considerably better than that of an ordinary radar. It lowers the improvement factor of MTI radar. Following are some of its causes:
   - i) Pulse to pulse changes in amplitude, freq or phase of xmitter signal.
   - ii) changes in stalo or coho ~~receivers~~ oscillators in the receiver
   - iii) jitter in timing of pulse transmission (iv) variations in the time delay through delay lines.
   - iv) changes in pulse width.

This causes can limit the performance of MTI radar

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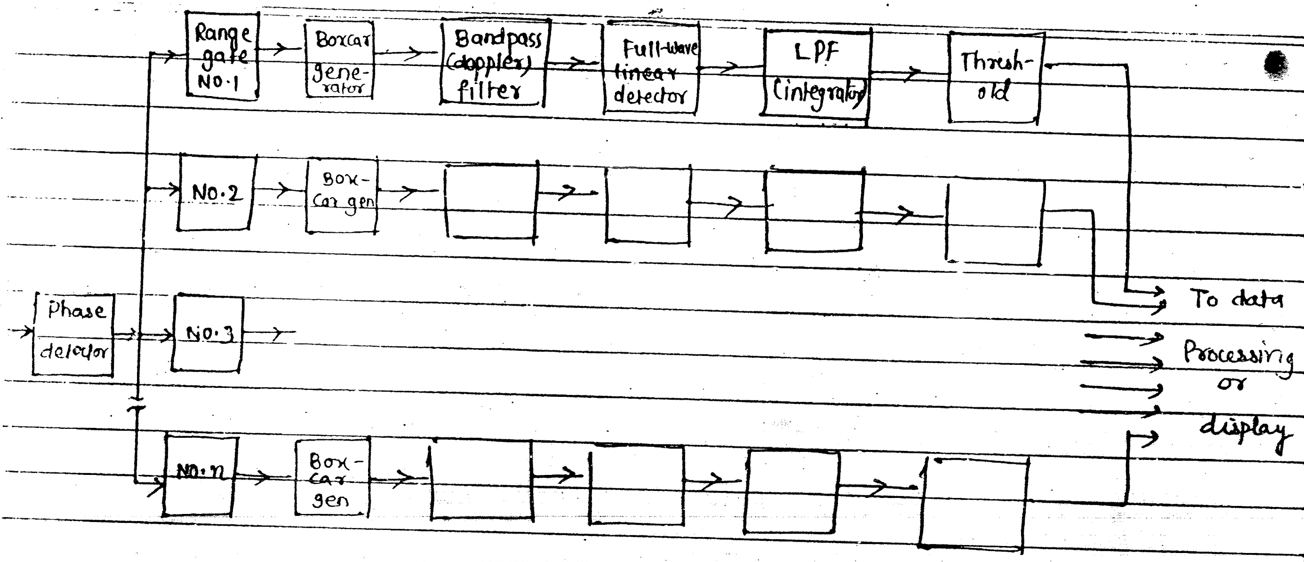

2) The range gate acts as a switch which opens and closes at proper time. It opens in sequence long enough to sample voltage of video waveform; corresponding to a different range interval in space.

3) The range gates are activated one each pulse-repetition interval.

4) The o/p of 6 for stationary target is in series of pulses of constant amplitude. An echo from a moving target produces a series of pulses which vary in amplitude according to the doppler frequency.

5) The o/p of the range gates is stretched in a ckt called a boxcar generator or sample & hold ckt whose purpose is to aid in filtering & detection process.

6) The clutter rejection filter is bandpass filter whose BW depends on extent of expected clutter spectrum.

7) The purpose of dectector is to convert the bipolar video to unipolar video which is the passed through integrator.

8) The integrator o/p is applied to threshold detection ckt. only those signals which cross the threshold are reported as targets.

9) o/p
PPI

Features
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Advantag

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first blind speed.

Disadvantage It is unable to cancel sound-time-around clutter echoes such clutter echoes does not appear at same range from pulse to pulse & thus produces uncanceled residue.

Elimination: second-time-around clutter echoes can be removed by use of constant prf providing there is pulse to pulse coherence.

Advantages
1) reduces effects of blind speeds.
2) Improved frequency response.

* Range-Gated Doppler filters:

Introdⁿ: The delayline canceler (time domain filter) has been widely used in MTI radar as means for seperating moving targets from stationary clutter. However its also possible to employ the more usual frequency domain bandpass filters to sort doppler freq shifted targets.

A narrowband filters with a passband designed to pass doppler freq components smears the i/p pulse since impulse response is approx. the reciprocal of filter BW. This results in
i) range resolution destruction
ii) collapsing losses
iii) redⁿ in sensitivity.

The losses in range ~~ra~~ information & collapsing losses may be eliminated by first quantizing the range (time) in to small intervals. This process is called range gating.

Block diagram: The block diagram of the video of MTI radars with multiple range gates ~~is~~ followed by ~~ma~~ clutter-rejection filters is shown & explained :-

1) The output of phase detector is sampled sequentially by the range gates.

* Multiple or Staggered, pulse repetition frequencies:

Introdⁿ : The pulse repetition frequency might be switched every other scan or every time the antenna is scanned a half beamwidth or the period might be alternated on every other pulse - when the switching is pulse to pulse it is known as a staggered prf.

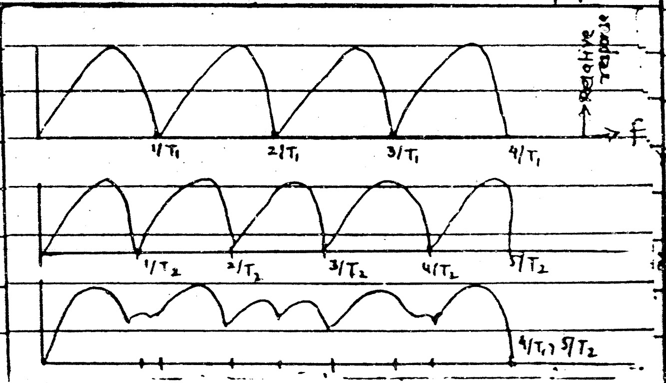
Explaination : 1) The use of more than one prf offers additional flexibility in the design of MTI doppler filters -

2) Multiple prf reduces the effect of blind speeds ③ The blind speeds of two independent radars operating at same frequency will be different if their prf's are different. Thus if one radar were blind to moving target it would be unlikely that the other radar would be "blind" also.

4) Instead of using two seperate radars, same result can be obtained by one radar which time shares its prf betⁿ two different values. Such a system is called multiple or staggered prf where switching is pulse to pulse.

5) Use of multiple prf's also allows a sharper low frequency cutoff in frequency response that ~~ma~~ might be obtained with cascade of single delay line cancellers -

Example : An example of composite response of an MTI radar operating with two seperate prf's on time shared basis is shown below. The prf's are in ratio 4 : 5.



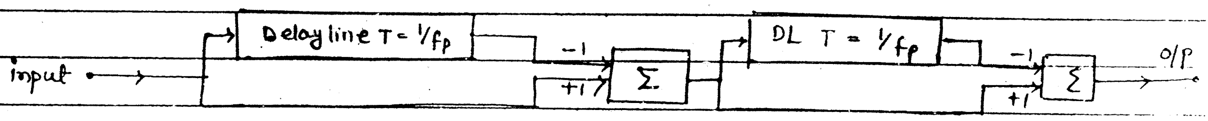
→ zero response occurs only when blind speeds of each prf coincide.

→ for given ex blind speeds are coincident if for $4/T_1 = 5/T_2$.

→ closer the ratio $T_1 : T_2$ approaches unity, the greater will be value of

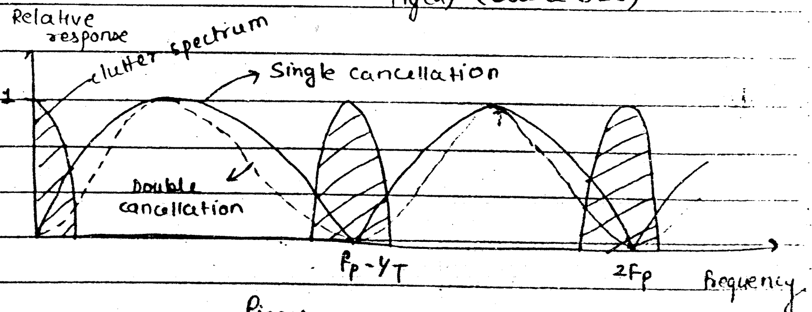
(W)

*** Double cancellation:** The frequency response of single delayline canceller doesnot have as broad a clutter rejection null as might be desired in vicinity of dc. It's response may be improved by passing it through second delay line canceler as shown below in fig. The output of this ~~over~~ entire configuration is square of that from a single canceler. Thus the frequency response is $4\sin^2 \pi f_d T$. such a configuration is called double delay line canceler or simply a double canceler

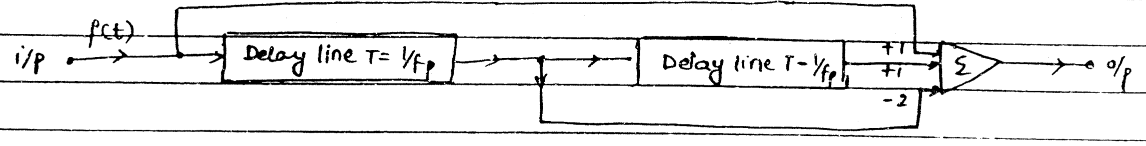


fig(a) (Double DLC)

It's response shown here. The configuration shown in fig(c) is known as a two-delay-line configuration and has same frequency response char. as double dlc.



fig(b)



fig(c) [two-delay line configuration / Three pulse canceler]

operation A signal f(t) is inserted in to adder along with signal from preceding pulse period with its amplitude weighted by factor -2, pulse the signal from two pulse period previous. The o/p of adder is thus

$$f(t) - 2f(t+T) + f(t+2T)$$ which is also the response of delay line canceler.

to be same as the prf or its multiple. Those relative target velocities result in zero MTI response & are called blind speeds given by

$$\boxed{v_n = \frac{n\lambda}{2T} = \frac{n\lambda f_p}{2}} \quad n = 1, 2, 3 \quad \text{where} \quad \lambda = \frac{c}{f}$$

v_n = nth blind speed.

If ~~v~~ λ = mts, f_p in Hz then v_n is in knots and

$$\boxed{v_n \approx n\lambda f_p \text{ knots}}$$

If the first blind speed is to be greater than maximum radial velocity expected from target, the product λf_p must be large. Thus MTI radar must operate at longer wavelengths (low freq) or with high prf or both.

The presence of blind speeds within the doppler frequency band reduces the detection capabilities of the radar.

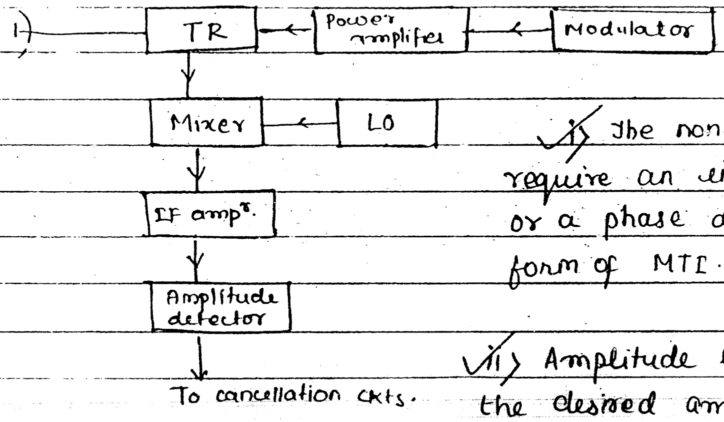
Elimination : 1) Blind speeds can sometimes be traded for ambigous range, so that in systems applications which require good MTI performance the first blind speed might be placed outside the range of expected doppler frequencies if ambigous range can be tolerated.

2) Effect of blindspeeds can be significantly reduced, without incurring range ambiguities by operating with more than one prf. This is called staggered-prf MTI.

3) operating at more than one RF frequency can also reduce the effect of blind speeds.

features are explained :

1)



i) The noncoherent MTI radar does not require an internal coherent reference signal or a phase detector as does the coherent form of MTI.

ii) Amplitude limiting is not applied else the desired amplitude fluctuations will be lost.

iii) IF ampr must be linear or if large dynamic range is reqd it can be logarithmic which → provides protection from saturation.

iv) The detector following ~~the~~ IF ampr is conventional amplitude detector.

v) The local oscillator of non coherent MTI does not have to be frequency stable as in coherent MTI

vi) The transmitter must be sufficiently stable over the pulse duration to prevent beats betn overlapping ground clutter but this is not as severe a requirement as in case of coherent radar.

vii) The o/p of the amplitude detector is followed by an MTI processor such as delay line canceler.

Advantages 1) Simplicity
2) requires less space & its weight is also limited.
3) Less costly

Disadvantages 1) The chief limitation is that the target must be in presence of relatively larger clutter signals if moving target detection is to take place.

2) The clutter serves as same f^n as reference signal in coherent- MTI.

Thus if clutter were not present the desired targets would not be detected.

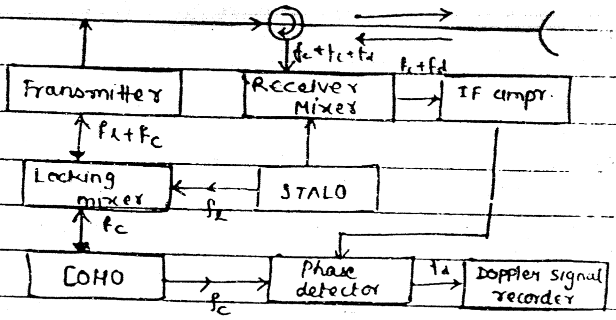
s) Improvement factor is not as good as coherent MTI.

* Pulse doppler radar:

Introdⁿ: A pulse radar that extracts the doppler frequency shift for the purpose of detecting moving targets in the presence of clutter is either MTI radar or pulse doppler radar. However the difference betⁿ the two is; MTI usually refers to a radar in which the pulse repetition frequency is chosen low enough to avoid ambiguities in range but with consequence that frequency measurement is ambigous & results in blind speeds.

The pulse doppler radar on the other hand is a radar in which Prf is chosen high enough to avoid blind speeds, but it experiences ambiguities in range.

Block diagram: The block diagram of pulse doppler radar is shown below & explained further:



Explaination point (ii) to (vii) of MTI radars with using power ampr.

Now, According to sampling theorem the PRF of the pulses transmitted is equal to sampling rate which is given by Nyquist rate i.e

$$\boxed{PRF \geq 2f_d}$$

∴ Doppler frequency shift is given by $f_d \leq \frac{PRF}{2} = \frac{1}{2T}$ where T = interpulse period ——— ①

Thus, highest doppler freq shift is $f_{dmax} = \frac{PRF}{2}$ ——— ⑪

If the electromagnetic wave emitted by the antenna has a phase ϕ_0 the phase of the received echo will be

$\phi = \phi_0 + \frac{2\pi}{\lambda} \times 2r$ r = range of target

Also the rate of change of phase = Doppler shift of freq ω_d

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

$$\Rightarrow \boxed{f_d = \frac{2v_r}{\lambda}} \quad \text{——— ③}$$

eqⁿ ③ is same as derived for MTI radars.

combining ① and ③

$$\frac{2v_r}{\lambda} \leq \frac{PRF}{2}$$

$$\boxed{v_{r\,max} = PRF\left(\frac{\lambda}{4}\right)} \quad \text{——— ④}$$

Thus max ~~radial~~ vel is prop. to product of PRF & wavelength.

Thus to measure higher velocities a longer wavelength & higher PRF must be employed. *

Also max unambigous range of pulse radar is given by 1

$$r_{\substack{max\\unamb}} = \frac{1}{2}\left(\frac{c}{PRF}\right) \quad \text{——— ⑤}$$

The max doppler shift of freq is related to $r_{max(unamb)}$ as (from ⑤ & ⑪)

$$f_{max} = \frac{1}{4}\frac{c}{r_{max(unamb)}} \quad \text{——— ⑥}$$

from ⑤ and ④

$$v_{r\,max} = \frac{c}{2\,r_{max(unamb)}} \times \frac{\lambda}{4}$$

or, $\boxed{v_{r\,max} = \frac{\lambda c}{8\,r_{max(unamb)}}}$

Advantages ~~1)~~ Ability to reject unwanted echoes either by range gating or by doppler selection.

2) Ability to measure range and velocity unambiguosly over predetermined limits, even in the presence of multiple targets.

3) coherent integration of echo pulses by doppler filter increases the $\frac{S}{N}$ ratio and echoes from greater range are detectable.

~~4)~~ No transmitter leakage (ad over CW radar). ~~5)~~ more capable of reducing clutter.

Disadvantage It's detection capability is is reduced because of blind spots in range resulting from high prf.

Applications
i) In detecting & estimating aircrafts motion
ii) For observing weather phenomena in airports as a meterological warning radar.
iii) To detect & measure turbulences in air.

* Other types of MTI:

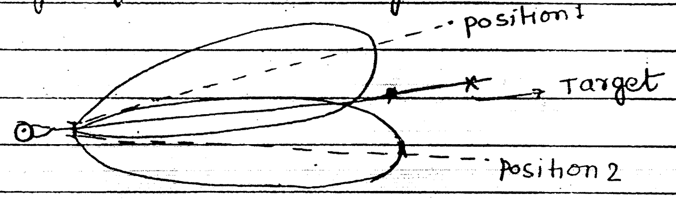
1 TWO FREQUENCY MTI : The first blind speed of an MTI radar is inversly proportional to carrier frequency. This can result in appearance of many blind speeds in conventional MTI radar that operate at the higher microwave frequencies. one method to increase first blind speed is to transmit two carrier frequencies f_0 and $f_0+\Delta f$ and extract the difference frequency Δf for MTI processing. The resulting blind speeds will be same as if the radar transmitted the difference frequency rather than carrier. For example if $\Delta f = 0.1f$ the first blind speed corresponding to differena frequency is 10 times that of MTI radar with carrier freq f_0.

A two freq MTI transmits pair of pulses at two seperate carrier frequencies. The two received signals are mixed in a non-linear device & the diff frequency is extracted for normal MTI signal proce-

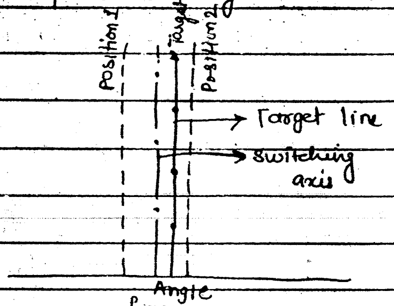
i) 8 In this method the ant^na^ beam is switched alternately between two positions such that there is overlap region ~~between~~ of the beams as shown in fig(a). (polar rep.) & fig (b) (rectangular repr.)

ii) The difference in amplitude between the voltages obtained in the two switched positions is a measure of the angular displacement of the target from the switching axis.

Que' Ans 8



(fig(a)).



fig(b)

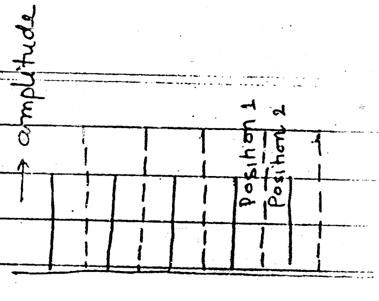
iii) When the two voltages in the two switched positions are ~~needed to obtain the angular error~~ equal, the target is on the axis and its position may be determined from the axis direction. Any deviation from this line will make amplitudes unequal.

iv) To obtain error signal capable of actuating the ant^na^ driver motor the sign of the error must change for target positions on either side of the equisignal line. This can be accompolished by

- a) detecting amplitudes of two positions.
- b) seperating into two channels 1 and 2 corresponding to positions 1 and 2.
- c) converting to dc signals representing the peak amplitude of echo for two channels.
- d) substracting the dc o/p of one channel from that of other.

v) The error signal is represented as shown in fig ©.

Applications Sequential lobing was one of the first tracking radar techniques to be employed. Early applications were in airborne-interception radar & ground-based aircraft fire control radar, But it is no longer used in modern radar tracking applications.



Fig(c).

Que: How it is improvement over merely pointing antenna accurately at the target?

Ans: The tracking radar must first find its target before it can track. Although it is possible to use a single radar for both the search & the tracking functions, such a procedure usually results in certain operational limitations. obviously, when the radar is ~~put~~ used in its tracking mode it has no knowledge of other potential targets.

Also, if antenna ~~be reqd~~ pattern is a narrow pencil beam & if search volume is large, a relatively long time might be reqd to find the target. Thus sequential lobing technique is ~~more~~ an improvement over merely pointing ant^na^ accurately at target.

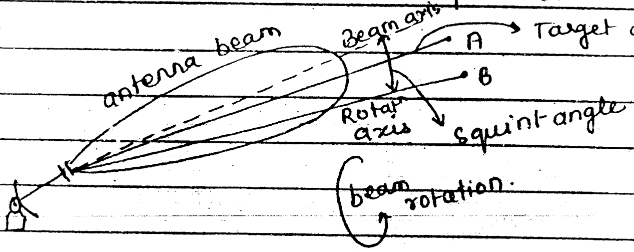
Also one of the limitations of a simple unswitched nonscanning pencil beam ant^{na} is the angle accuracy can be no better than the size of antenna beamwidth. In seq. lobing, the target position accuracy can be far better than that given by ant^{na} beamwidth.

✳ CONICAL SCAN:

→ same introdⁿ.

→ This method of tracking is explained below:

i) In this method instead of switching the antenna between two positions as in Lobe switching, the beam position can be steered continously; making the beam axis trace out a cone in space in the target region as shown in fig(a).



(Fig a; conical scan tracking beam)

ii) For a conical scan, the beam axis is changed by an angle called as squint angle (defined as angle between the axis of rotation and the axis of antⁿᵃ beam) and rotated about the axis of dish (axis of rotatⁿ of beam).

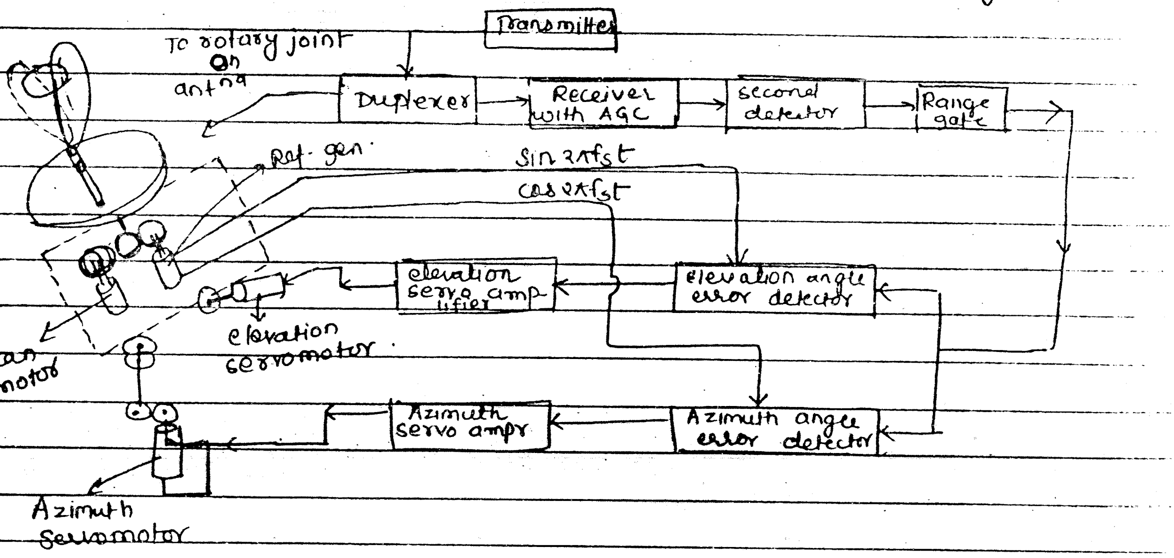
iii) If the target happens to coincide with the axis of rotation then conical scan motion of the beam axis will not produce any change in the echo intensity which will however be smaller as compared to what is expected for the target position on the beam axis.

iv) The amplitude of echo signal modulation will depend on the shape of antⁿᵃ pattern, the squint angle & angle betⁿ target line of sight & rotatⁿ axis.

v) The phase of modulation depends on angle betⁿ target & rotatⁿ axis.

Advantages
i) It suffers less loss than sequential lobing
ii) The ant^na & feed systems are usually less complex.
iii) less costly :

Conical scan tracking radar: A schematic diagram of a conical scan radar is shown below. It is explained in following points :-



i) A generator driven by a gear coupled to the rotating gear of the subreflector, generate two sinusoidal reference signals at the rotation frequency f_s, 90° out of phase with each other i.e $\sin 2\pi f_s t$ & $\cos 2\pi f_s t$.

ii) These are applied to pair of phase sensitive detectors ~~for~~ with incoming echo intensity received through range gate of radar receiver.

iii) one of the detectors produces a dc voltage proportional to elevation angular error and other to azimuthal angular error.

iv) These error signals are amplised by servo amprs to drive the azimuth and elevation drive motors of ant^na in dir^n so as to correct the respective errors automatically by servofeedback control system so as to direct the axis of rotation of beam towards the target with very small residual error.

v) A minimum residual error is inevitable in any feedback control system.

vi) The positions of the rotation axis of the ant^na beam in elevation and azimuth are dilplayed by making use of standard angle transducers like synchros, potentiometer etc.

Automatic gain control (AGC): The echo signal amplitude at the tracking radar received will not be constant but will vary with time, due to following reasons :-

i) The inverse fourth power relationship bet^n echo signal and range.
ii) The conical scan modulation.
iii) amplitude fluctuations in target cross-section.

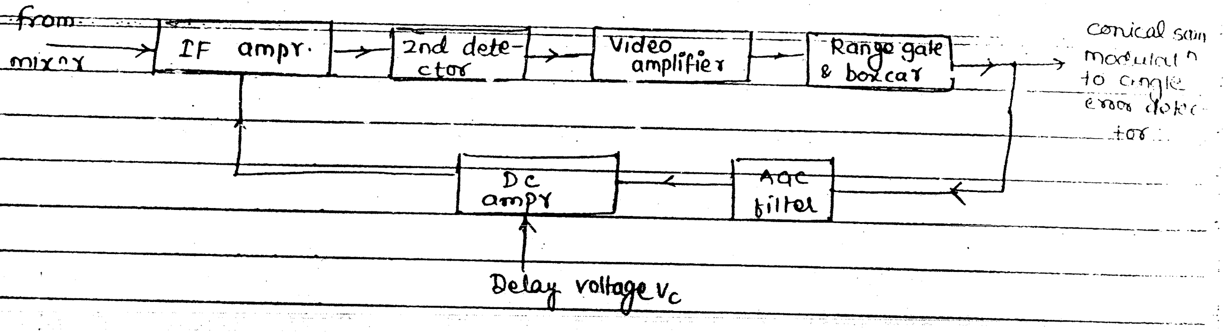
The function of AGC is ① To maintain the dc level of the receiver o/p constant ~~and~~ ② To smooth or eliminate as much of the noise like amplitude fluctuations as possible.

③ To prevent saturation by large signals which may result in loss of scanning modulation.

An example of the AGC portion of a tracking-radar receiver is shown below in fig. A portion of video amplifier o/p is passed through a ~~LPF~~ low pass or smoothing filter and fed back to control the gain of IF amplifier. The larger the video o/p, the larger will be the feedback signal and greater will be gain reduction.

A

Boxcar genʳ:

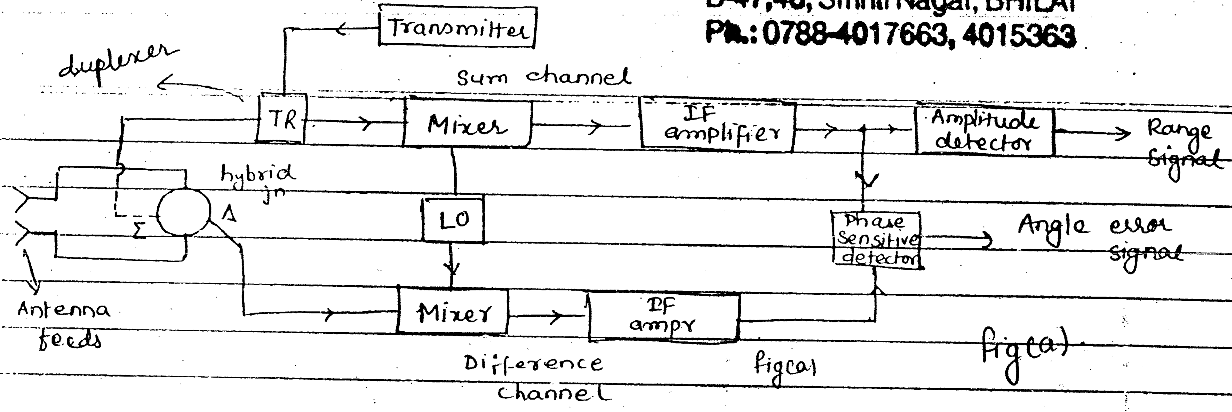


* MONOPULSE TRACKING RADAR:

Introdⁿ: The conical-scan and sequential lobing tracking radars require a minimum no. of pulses in order to extract the angle error signal. During measurement time, the train of echopulses must contain no amplitude modulation components other than modulation produced by scanning, which if present is serious in some applications to limit the accuracy of tracking radar.

Pulse to pulse amplitude fluctuations of the echo signal have no effect on tracking accuracy if angular measurement is done on basis of one pulse rather than many. In these method more than one antⁿᵃ beam is used simultaneously in contrast to the conical scan or lobe switching tracker which utilizes one antⁿᵃ beam on time shared basis. The angle of arrival of the echo signal may be determined in a single pulse system by measuring the relative phase or the relative amplitude of the echo pulse received in each beam. All the information necessary to determine the angular error is obtained on the basis of singlepulse; hence the name monopulse radar.

Amplitude Comparasion Monopulse: The amplitude comparasion monopulse employs two overlapping antⁿᵃ patterns to obtain angular error in one coordinate. It's block diagram is shown in fig(a) & explained :-



fig(a).

i) The two adjacent antna feeds are connected to the two arms of hybrid junction as shown.

ii) on reception the o/p's of the sum arm and the difference arm are each heterodyned to an intermediate frequency & amplified.

iii) ~~As~~ The transmitter is connected to the sum arm

iv) Range information is also extracted from the sum channel.

v) A duplexer is included in the sum arm for the protection of the receiver.

vi) The o/p of the phase-sensitive detector is an error signal whose magnitude is proportional to the angular error & whose sign is proportional to the direction.

vii) The sign of difference signal (error sig) is determined by comparing ~~with~~ the phase of the ~~sum~~ diff signal with phase of sum signal.

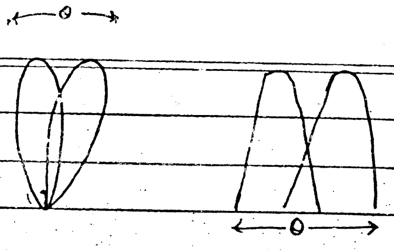
monopulse antenna patterns & error signals

i) The two overlapping antna beam (shown in fig b) may be generated by a single reflector or with lens antna illuminated by two adjacent feeds.

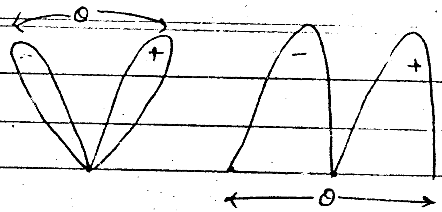
ii) The sum of two antna patterns of fig b is shown in fig (c) and their difference is shown in fig(d).

iii) The sum patterns is used for transmission & the difference patterns are used for reception.

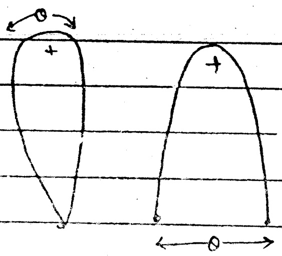
iv) The signal received with difference pattern provides magnitude of the angle error.



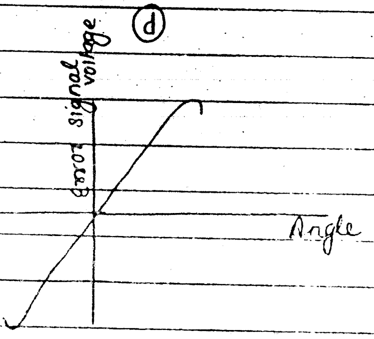
(b)



(d)



(c)



(e) (error signal char.)

v) The sum signal provides the range measurement and is also used as a reference to extract the sign of the error signal.

vi) signals received from sum and the difference patterns are amplified seperately and combined in a phase sensitive detector to produce error signal characteristics shown in fig(e).

Bloot: Amplitude-Comparsion monopulse radar in two co-ordinate:

A block diagram of monopulse radar with provison for extracting error signals in both elevation and azimuth is shown in fig① below. It's working is explained:-

i) The cluster of four feeds generates four partially overlapping antⁿᵃ beams.

ii) All four feeds generate the sum pattern.

iii) The difference pattern in one ~~phase~~ plane is formed by taking the sum of two adjacent feeds & substracting this from the sum of the other two adjacent feeds.

$$\Delta R = \frac{2h_a h_t}{R} \quad \text{where}$$

h_a = radar ant^{na} height.

h_t = target height , R = range to the target.

(X) The basic reason for poor tracking at low angle results from the fact that the conventional tracking radar with a two-horn feed in elevation provides unambigous information for, only one target.

(X) At low elevation angles two targets are presents, the real one & its image. Thus aperture must be provided with more degrees of freedom.

* TRACKING IN RANGE:

Introdn: In most tracking radar applications the target is continously tracked in range as well as in angle. Range tracking might be accompolished by an operator who watches an A-scope or J-scope presentation & manually positions a handwheel in order to maintain a marker over desired target pip. As targets speeds increase, it is increasingly difficult for an operator to perform at necessary levels of efficiency over a sustained period of time & automatic tracking becomes a necessity.

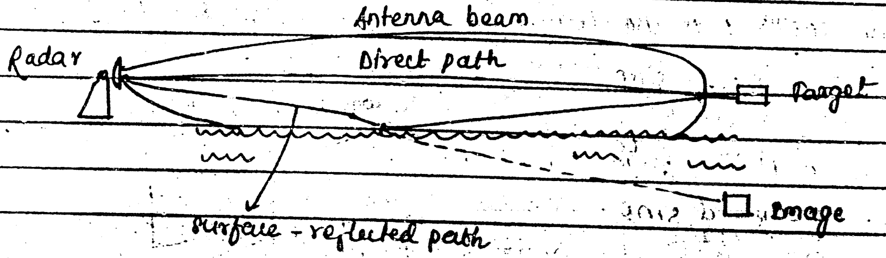
Explaination The technique for automatically tracking in range is based on the split range gate. Two range gates are generated as shown in fig below & explained:

i) one is the early gate & other is the late gate.

ii) The echo pulse is shown in fig ⓐ, the relative position of the gates at a particular instant in fig ⓑ & error signal is shown in fig ⓒ.

iii) ~~The~~ portion of the signal energy contained in the early gate is less than

* **Low-angle tracking :** A ~~tood~~ radar that tracks a target at a low elevation angle near the surface of earth can receive two echo signals from target; The figure illustrating the lowangle tracking is shown below in fig :-



i) Of the two echo signals received, one signal is reflected directly from the target & other arrives through the earth surface.

ii) The direct and the surface reflected signals combine at the radar to yield an ~~image~~ angle measurement that differs from true measurement that would have made with a single target in absence of surface reflections.

iii) The result is an error in the measurement of elevation.

~~iv) The result is an error in the measurement~~

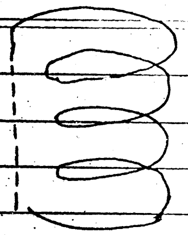
iv) The surface reflected signal may be thought of as originating from the image of the target mirrored by the earth surface.

v) The surface reflected signal is also called multipath signal.

vi) The surest ~~as~~ method for avoiding tracking error due to multipath signal ~~is~~ via earth surface is to use ant^na^ with such a narrow beamwidth that it does not illuminate the surface. This requires a large ant^na^ and/or a high frequency.

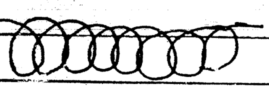
vii) The surface reflected signals travel a longer path than the direct signal so that it may be possible in some cases to seperate the two in time (range). ⓥⅲⅰ Tracking on direct signal avoids the angle errors introduced by the multipath. The range-resolution reqd to seperate the direct from the ground reflected signal is

i) <u>Helical scan</u> : In the helical scan, the ant^{na} is continously rotated in azimuth while it is simultaneously raised or lowered in elevation. It traces a helix in space.



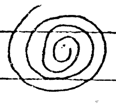
(Trace of helical scanning beam).

ii) <u>palmer scan</u> : It consists of a rapid circular scan about the axes of

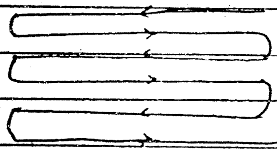


the ant^{na}, combined with a linear movement of the axes of rotation. when the axes of rota^{n} is held stationary, palmer scan reduces to conical scan. It is suited to search area which is larger in one dimension than another.

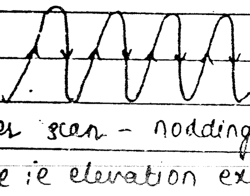
iii) <u>Spiral scan</u> : The spiral scan covers an angular search volume with circular symmetry. ~~Both the Spiral scan.~~ and Both palmar & spiral scan suffer from disadvantage that all parts of scan volume donot receive same energy unless the scanning speed is varied during the scan cycle.



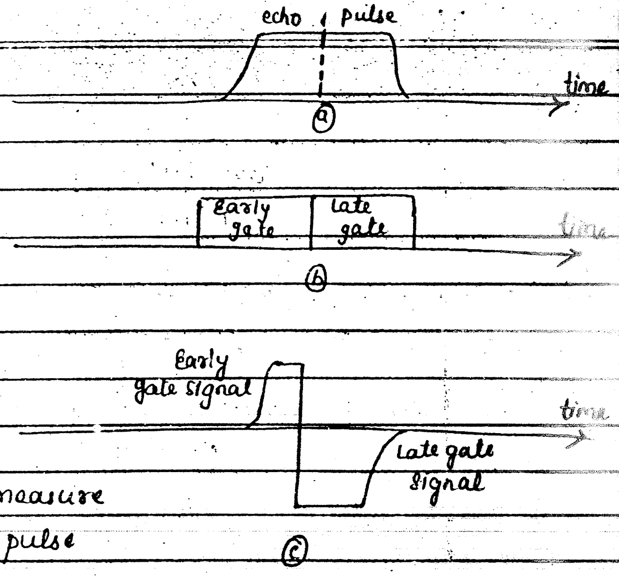
iv) <u>Raster or TV scan</u> : It paints the search area in a uniform manner. The raster scan is simple & convenient means for searching of a limited sector, rectangular in shape.



v) <u>Nodding scan</u> : nodding scan is produced by oscillating the ant^{na} beam rapidly in elevation & slowly in azimuth. Although it may be applied to cover a limited sector, as does the raster scan - nodding scan may also be used to obtain hemispherical coverage i.e elevation extending up to 90° & azimuth scan angle to 360°



acquisition - act of aquiring or gain



is the lategate.

iv) The portion of the signal energy contained in the early gate is less than that in the late gate.

v) If the o/p's of the two gates are substracted an error signal (fig c) will result which may be used to reposition the center of the gates.

vi) The magnitude of error signal is measure of difference betⁿ the center of the pulse and the center of the gates.

vii) The sign of the error signal determines the direction in which the gates must be repositioned by a feedback-control system. when the error signal is zero, the range gate are centered on the pulse.

Advantages:

i) It isolates one target, excluding targets at other ranges which permits the boxcar generator to be employed.

ii) Range gating improves the signal to noise ratio since it eliminates the noise from other range intervals.

iii) minimizes extraneous noise.

ACQUISITION : A tracking radar must first find and aquire its target before it can operate as a tracker. Therefore it is usually necessary for the radar to scan an angular sector in which the presence of the target is suspected. Most tracking radars employ a narrow pencil beam antenna. Examples of the common types of scanning patterns employed with pencil beam antennas are explained below:

U-5

① Displays

Purpose → to present the radar echo signal in form suitable to ~~displ~~ be interpreted by operator.

* when connected directly to video o/p of reciver, information displayed is called raw video.

when receiver video o/p is first ~~ds~~ processed by automatic detector then o/p displayed is called Synthetic video.

CRT → * universally used display.

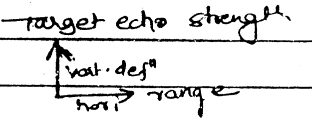
* Two basic CRT displays

Intensity modulated (PPI) → Target is indicated by intensifying the e⁻ beam & presenting luminous spot on face of CRT. → blip. → Presents data in more convienient way.

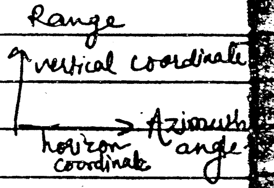
Defl^n modulated. (A scope) → target is indicated by defl^n of e⁻ beam. → Simpler ckt

Types of CRT display

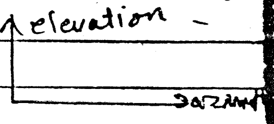
① A scope: (defl^n modulated) →



② B scope: (Intensity mod^d rectangular display)

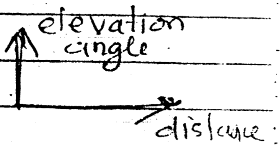


③ C-Scope (—— " ——)



④ D-scope : [is a C-scope in ~~[illegible]~~ which blips extends vertically to give rough est^mn of distance].

⑤ E-scope [intensity mod. rect. display]



⑥ F-scope → Rect display

→ Target appears as centralised blip when antna is armed at it.

→ Hor. & Vert. aiming errors are ind. by hori & vert disp. [illegible] of blip.

⑦ G-scope → Rect. display

→ -11- laterally -11- in azimuth

→ -11-

⑧ H-scope (B scope - modified to include indication of angle of elevation).

⑨ I-scope — target appears as complete circle when radar antna is pointed at it & radius of circle α target distance.

⑩ J-scope (modified A scope in which time base is circle & target appears as radial defl^ns from time base).

⑪ K-scope (Modi A scope in which target appears as pair of vertical defl^ns).

⑫ L-scope → target appears as two horizontal blips.

$$= \frac{P_t G^2 \sigma R_j^2 B_j}{4\pi r^4 B P_j G_j G'}$$

$$\therefore \quad r^4 = \frac{P_t G^2 \sigma R_j^2 B_j \times J}{4\pi B P_j G_j G' S_{min}}$$ is range eq^n in presence of jammer

For self screening jammer $R_j = r$ and $G' = G_j$

$$r^2 = \frac{P_t G \sigma B_j J}{4\pi B P_j \cdot G_j S_{min}}$$

ECCM. It is method of over coming ECM ie jamming of radar
see book.

→ use frequency agility → changes radar freq $\overset{\text{oper.}}{}$ unpred. manner

→ $\theta = \frac{1.22\lambda}{D}$ ✓

Normal Luis
lewis

Aberrant : Abnormal or deviant : He always behaves Aberrantly.

Eclat : brilliant success : He got Eclat because of ~~for~~ his hard work.

Iconoclastic : attacking cherished tradations : History w

palliate : to ease pain : you can use this pills to palliat the pain

Raiment : clothes : Raiment should always suit your personality.

jaunt : a short trip : ~~we should with~~ Let's go for a jaunt.

Panacea : cure : wine is not panacea to all the problems.

Rankle : irritate : Don't Rankle me.

Ablution washing : He make loud noises in his daly ablutions.

Camaraderie : friendship :

Imbecility : weakness of mind.

⑬ M-scope — modified A-scope. for measuring distance
⑭ N-scope → Mod. K scope — " —

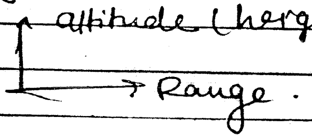
⑮ O-scope — mod. A scope.

⑯ PPI (P-scope) (Plane position indicator :)

→ intensity mod. display
→ circular
→ In this echo signals produced from reflecting objects are shown in plan position with range & azimuth angle displayed in polar co-ordinates.

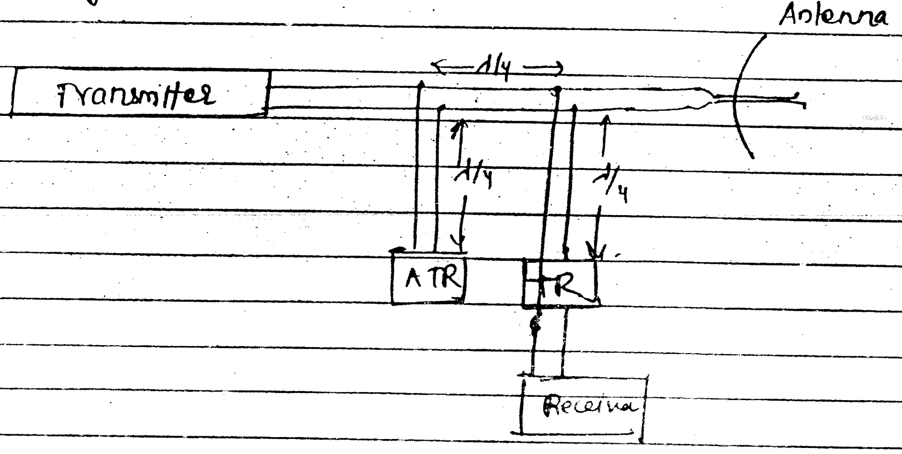
⑰ R-scope :- is A scope with segment of time base expanded near blip for greater accuracy in distance measurement.

⑱ RHI or Range height indicator : intensity modulated display



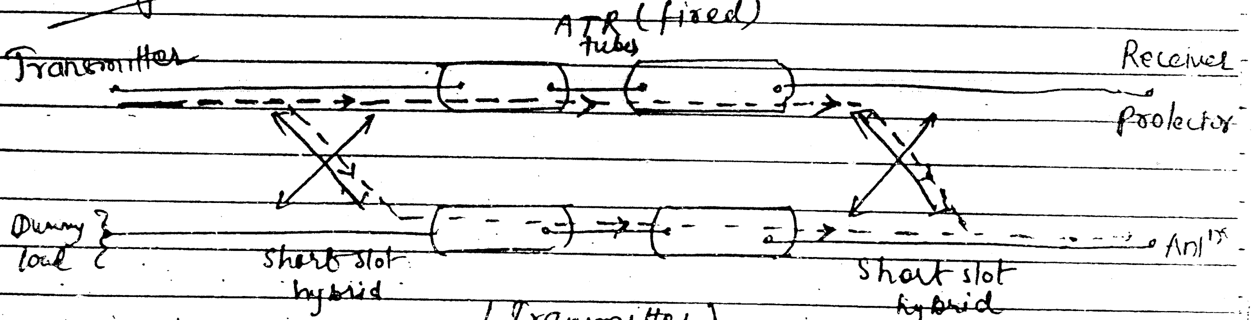
Duplexer p 144

Branch type

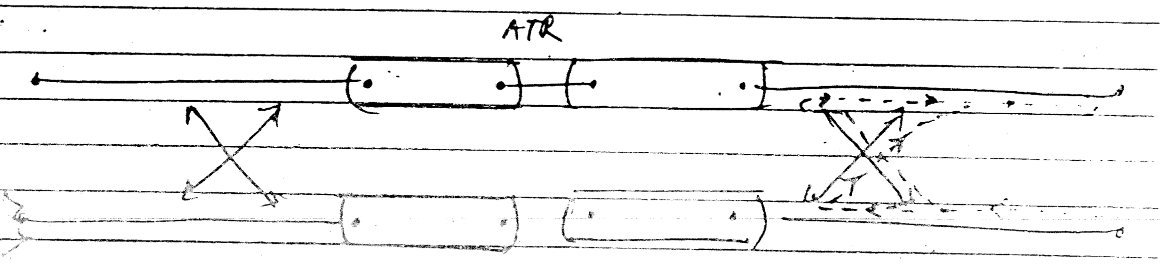


Balanced Duplexer based on short slot hybrid fn.

~~Using ATR~~

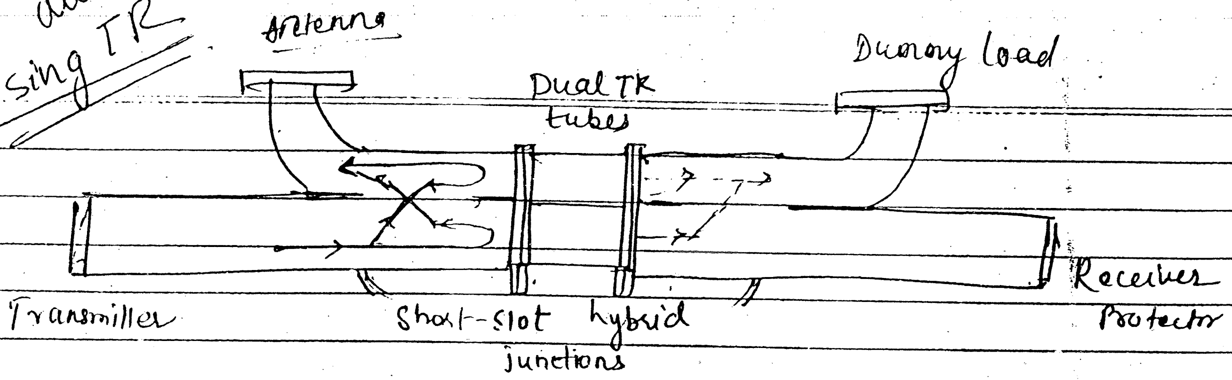


(Transmitter)

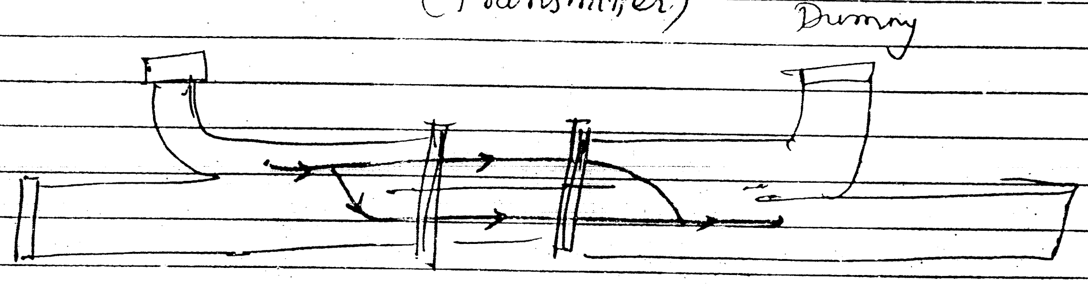


(Reception)

Using dual TR



(Transmitter)



Reciever

ECM Tech. for rendereing the radars of the enemys ineff. in~~for~~ det^n of target is ECM (Elec. countee Measures).
ECM can be active or passive.

active : The tech - called like jamming of enemy radars by ~~powerefal~~ transmitting powerful radio beams towards their radars is called as ~~&~~ active ECM.

passive ECM ECM which includes needles of metal thrown out ~~as~~ to scatter the enemy radar beams away from real target.

* Active ECM reduces the detection range of ~~rang~~ radar drastically.

The max^m range of pulse radar in absence of jamming

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

$$= \left[\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}}\right]^{1/4} \quad \text{—①} \qquad G = \frac{4\pi A_e}{\lambda^2}$$

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

If receiver noise $N_r = FKTB = N.B$ —② where

$N = FKT$ is noise power per H_z of BW.

∴ from ①

$$S_{min} = \frac{P_t \lambda G^2 A_e \sigma}{(4\pi)^3 r^4} \quad \text{—③}$$

③ ÷ ②

$$\frac{S_{min}}{N_r} = \frac{P_t G^2 \lambda^2 \cancel{A_e} \sigma}{(4\pi)^3 r^4 B N} \quad \text{—④}$$

In presence of jammer, if signal received from jammer is J

$$\frac{J}{N_r} = \frac{P_J G_J G' \lambda^2}{(4\pi)^2 R_J^2 B_J N} \quad \text{—⑤}$$

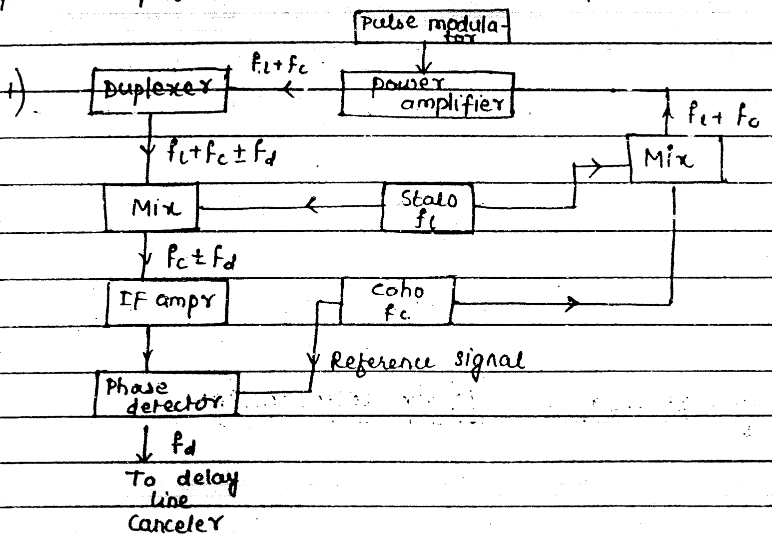
where subscripts P, G, R & B refers for jammer & G' is radar ant^{na} gain in dir^n of jammer.

$$\therefore \frac{S_{min}}{J} = \frac{P_t G^2 \cancel{\lambda^2} \sigma}{(4\pi)^{\cancel{3}} r^4 B\cancel{N}} \times \frac{\cancel{(4\pi)^2} R_J^2 \cancel{B_J} \cancel{N}}{P_J G_J G' \cancel{\lambda^2}}$$

* MTI Radar with power amplifier transmitter:

→ Introduce MTI radars.

→ Block diagram : The block diagram of more common MTI radar employing a power amplifier is shown below & explained :



(i) The significant difference bet^n this MTI configuration and basic MTI conf. is the manner in which reference signal is generated.

(ii) In this configuration the reference signal is generated by a coherent oscillator called coho - which is a stable oscillator whose frequency is same as the intermediate frequency used in the receiver.

(iii) The output of coho f_c is also mixed with local oscillator frequency f_l.

(iv) The local oscillator ~~most~~ is also a stable oscillator and is called stalo the function of which is to provide necessary frequency translation from IF to the transmitted (RF) frequency.

(v) The stalo, coho and mixer in which they are combined prior to any low level amplification are called the receiver exciter as they play dual signal is preserved in the reference signal which infact is the distinguishing feature of coherent MTI radar.

v) If the CW oscillator voltage is represented as $A_1 \sin 2\pi f_t t$ where A_1 is amplitude & f_t the carrier frequency, the reference signal is

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

and the doppler shifted echo voltage is

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

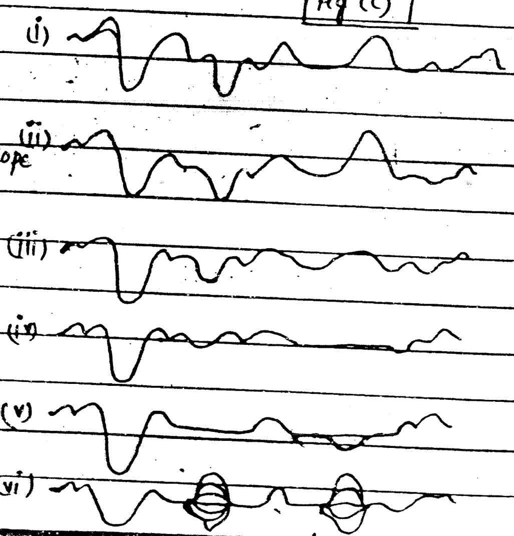
A_2 = amplitude of reference signal.
A_3 = amplitude of signal received from target at range R_0.
f_d = doppler frequency shift.
t = time. c = velocity of propagation.

vi) The reference signal & the target echo signal are heterodyned in the mixer stage of receiver. only low frequency component is of interest & is a voltage given by

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

vii) Moving targets can be distinguished from stationary targets by examining the video output on a A-scope (amplitude Vs range) in which single sweep on A-scope might appear [Fig c(i)]. Fig c(ii to v) are successive sweeps of. MTI radar. Fig c(vi) reveals superposition of many sweeps.
Arrows indicates position of moving targets.

Fig (C)



iv) The difference pattern in one plane is formed by taking the sum of two adjacent feeds & substracting this from sum of other two adjacent feeds.

v) The difference pattern in the orthogonal plane is obtained by adding the differences of orthogonal adjacent pairs.

vi) A total of four hybrid junctions generate the sum channel, the azimuth difference channel & the elevation difference channel.

vii) All three mixers operate from single local oscillator in order to maintain the phase relationship bet^{n} three channels.

viii) The phase sensitive detectors extract the angle error information, one for azimuth, the other for elevation.

ix) Range information is extracted from the O/p of sum channel after amplitude detection.

Phase Comparasion Monopulse:

→ same introd^{n}.

→ Fig & expl^{n} :

i) The angle of arrival (in one co-ordinate may also be determined by comparing the phase difference bet^{n} the signals from two separate antennas. This tracking
ii) radar is called phase comparasion monopulse.

ii) Unlike ant^{nas} of amplitude comparasion trackers, those used in phase-comparasion systems are not offset from the axis.

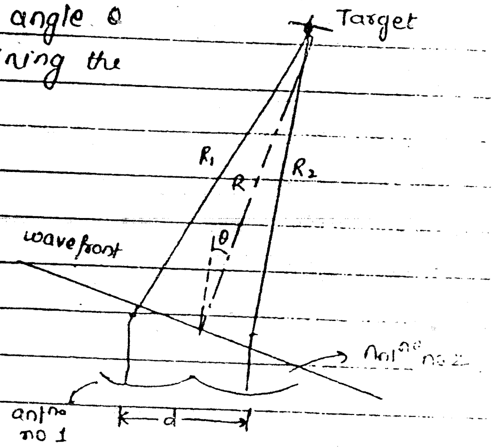
iii) The amplitudes of the target echo signals are essentially the same from each ant^{na} beam, but the phases are different.

iv) A tracking radar which operates with phase information is similar to an active interferometer & might be called as interferometer radar.

v) Fig below shows two ant^{nas} seperated by distance d.

vi) The distance to the target is R and is assumed large compared with ant^{na} seperation d.

VII) The line of sight to the target makes an angle θ to the perpendicular bisector of the line joining the two antnas.



VIII) The distance of antna 1 to the target is

$$R_1 = R + \frac{d}{2}\sin\theta$$

IX) The distance of antna 2 ~~from~~ to target is

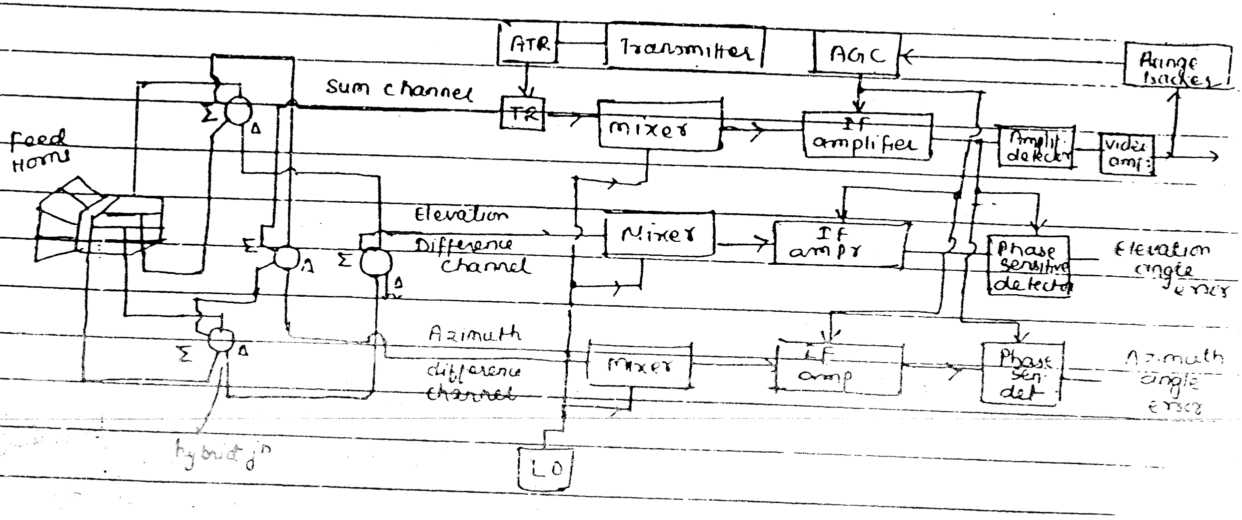
$$R_2 = R - \frac{d}{2}\sin\theta$$

*) The phase diff betn the echo signals in two antnas is approximately

$$\Delta\phi = \frac{2\pi}{\lambda} d\sin\theta$$

For small angles where sinθ ≈ θ, the phase difference is a linear fn of the angular error & may be used to position antna via a servo control loop.

* Fig(1) for Ampl. comp. monopulse with 2 co-ordinate :



$I_{2S} = \frac{f_p^2}{8\pi^4\sigma_c^4} \Rightarrow \boxed{I_{2s} = \frac{r_1 B^4}{3.853}}$ (double canceler)

4) <u>Limiting in MTI radar</u>: A limiter is usually employed in the IF amplifier just before MTI processor to prevent the residue from large clutter echoes from saturating the display. Ideally an MTI radar should reduce the clutter to a level comparable to receiver noise. However when MTI improvement factor is not enough to reduce the clutter sufficiently, the clutter residue will appear on the display and prevent the detection of aircraft targets whose crosssections are larger than clutter residue. This condition may be prevented by setting

$\frac{L}{N} = I$ I = imp. factor
L = limit level   N = Noise.

→ ~~Unfortunately~~ However nonlinear devices such as limiters have sideeffects that can degrade performance

→ Also, the loss of improvement factor increases with increasing ~~velocity~~ complexity of of the canceler.

→ Limiter need not be used if the MTI is linear over entire range of clutter signals and if the processor has sufficient improvement factor to reduce largest clutter to noise level.

* <u>Some imp. terms</u>:

<u>MTI improvement factor</u>: It is the ratio of signal to clutter ratio at the o/p of MTI system to the signal to clutter ratio at i/p, averaged uniformily over all target radial velocity of interest.

<u>Subclutter visibility</u>: The ratio by which the target echo power may be weaker than coincident clutter echo power and still be detected with specified detection & false alarm probabilities.

3. clutter visibility factor: The signal-to-clutter ratio after cancellation or doppler filtering that provides stated probabilities of detection & false alarm

4. clutter attenuation: The ratio of clutter power at canceler input to clutter residue at o/p, normalized to the attenuation of single pulse passing through the unprocessed channel of the canceler.

5. clutter residue: It is the clutter power remaining at the o/p of the MTI system.

6. Cancellation ratio: It is the ratio of canceler voltage amplification for the fixed target echoes received with a fixed antna to gain for a single pulse passing through the unprocessed channel of canceler.

7. **Interclutter visibility**: The ability of an MTI radar to detect moving targets which occur in the relatively clear resolution cells betn patches of strong clutter.

* Non coherent MTI :

Introdn: The coherent MTI & pulse doppler radar make use of phase fluctuations in the echosignal to recognize the doppler component produced by moving target. Their operation depend upon a reference signal at the radar receiver that is coherent with the transmitter signal.

However it is also possible to use the amplitude fluctuations to recognize the doppler component produced by moving target. MTI radar which uses amplitude instead of phase fluctuations is called noncoherent MTI or externally coherent MTI.

Blockdiag & features. The block diag of noncoherent MTI is shown below : 15