UNIT-1

History.

1886-1888 → Hertz → Radiowave communication
1903-1904 → Christian → collision avoidance CW
1922 → Marconi → angle-only CW to avoid collision.
1924→1926 → Pulse radars.
1930 → Hyland → Aircraft detection
1934 → Range → short pulse echo from aircraft.
1937 → Watt → home radar
1941 → USA – early morning radars, FM radars.
WW II – control, remote sensing, locatn of enemy aircraft.
1945 → VHF radar – dipole array antenna
USA/UK – used magnetron based microwave radar.

- CW radar → (continuous wave radar) → transmits high freq sig continuously.
- MTI radar → (moving target indicator) → uses doppler freq shift for discriminating moving target & stationary objects.

Band

HF	3-30MHz	Telephone
VHF	30-300MHz	TV, Satellite comm, FM
UHF	300-1000MHz	
L	1GHz - 2GHz	TV, Sat, Navigatn
S	2-4GHz	Sat / microwave.
C	4-8GHz	
X	8-12GHz	
Ku	12-18GHz	
K	18-27GHz	
Ka	27-40GHz.	
mm	40-300GHz	Radar comm.

- clutter → unwanted echo from the objects other than the target.
- pulse radar → transmits high power of a freq pulse. after transmitting 1 pulse, it receives echoes and then transmits another pulse. It determines dist, directn & altitude of an object.

• monostatic → transmitter receiver are at the same location with common antenna.

• bistatic → transmitter & receiver are at diff loc. & receiver receives slg from both transmitter & target.

Radar → electromagnetic s/m for detection and location of objects.

→ transmitting – pulse modulated sine wave.
– detects nature of echo slg.

→ transmitter – antenna → emitting EM wave generated by an oscillator.

→ Receiver → antenna
energy detecting device.

Target → part of transmitted signal. intercepted by a reflecting object.
→ re-radiated in all directions.

→ Rr → processes the slg, detect the presence of target → location
velocity.

Distance to the target → time taken for radar slg to travel to the target and back.

(direction of arrival)
→ Direction – angular position DOA of reflected wave using narrow beam antenna.

Doppler Shift → measure the target relative velocity and to distinguish moving from stationary ones.

cont.
→ indication of the target.
rate of change of position
→ track target movement

→ radar sig train of narrow, rectangular shaped pulses modulating a sine wave.

$\boxed{R = \frac{cT_R}{2}}$ ← range.

T_R → time taken by the pulse to travel to the target and return.

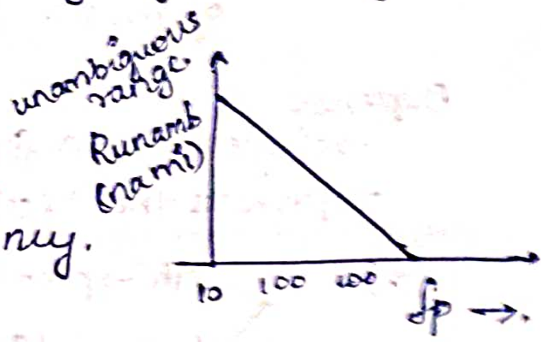
$R(km) \rightarrow 0.15 T_R (\mu s)$ or $R(nm) = 0.081 \; T_R (\mu s)$.

≈150 mts.

- Echos that arrive after a transmission of the next pulse these are called <u>second time around echos</u>.
- the pulse transmission rate is determined by the longest range at which targets are expected.
- the range beyonde ~~to~~ which targets appear as second-time-around echoes. is called maximum ~~ambiguity~~ unambiguous range.

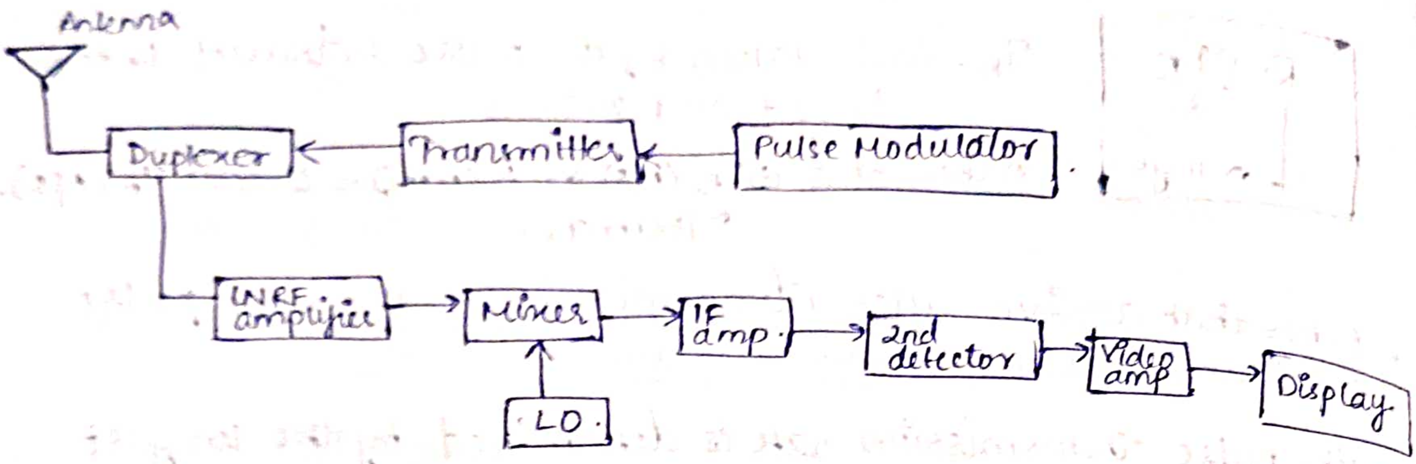
$$\boxed{R_{unamb} = \frac{c}{2f_p}}$$

f_p → pulse repetition frequency.



- the technique of using ~~non~~ long modulated pulse. to obtain resolutn of a short pulse but with the energy of a long pulse is called <u>pulse compression</u>.
- cw radar separates received echo from transmitted sig and the echos from stationary clutter.

20/01/23 Block Diagram of Pulse Radar.



Transmitter
→ oscillator
magnetron - pulsed by the modulator - repetitive throw of pulses.

Duplexer
→ single antenna for Txn and Rxn.
→ protects the receiver from HPT.

TR → protects receiver
ATR → directs the echosignal to the receiver during reception.
anti TR

Phase spectrum of MF
- -ve of PS of echosig.

LNA (Low noise amp).
→ amplify RF
→ sensitive, mixer i/p - dynamic range, less vulnerability to interference.

Mixer + LO →
RF → IF.

IF amp → matched filter - H(f) maximise the peak SNR at o/p.

Second detector.
→ Video amp to display on CRT / PPI (Plan position Indicator)

Mag freq response ⇒ |H(f)|
mag of echosig = |S(f)|.

Predition of Range performance (RANGE EQUATION).

relates the range of radar → Tr, Rr, antenna, target & envt.

P_t → transmitted power.
radiated by an isotropic antenna.

Power density at a distance R from the radar = $\dfrac{\text{radiated power}}{\text{surface area}} = \dfrac{P_t}{4\pi R^2}$ —— (1) w/m^2.

Maximum gain G of an antenna.

$$G = \frac{\text{max power density radiated by directive antenna}}{\text{power radiated by a lossless isotropic antenna with same } P_{input}}$$

Power density at range R from a directive antenna

$$= \frac{P_t G}{4\pi R^2} \quad \text{—— (2).}$$

- Target intercepts a portion of incident energy and reradiates in various directions.
- Power radiated in the direction of radar is needed.
  ↳ radar cross-section of target — σ
- Re-radiated power density at radar

$$\frac{P_t G}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2} \quad \text{—— (3).}$$

- Power received by radar $P_r = \dfrac{P_t G}{4\pi R^2} \cdot \dfrac{\sigma}{4\pi R^2} \cdot A_e$ —— (4).

- The max range of a radar R_{max} is at a distance beyond which target cannot be detected. this occurs when P_r = the min. detectable sig (S_{min}).

$$S_{min} = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4} \quad \text{—— (5).}$$

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

$$\boxed{R = \left[\frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}}\right]^{1/4}} \quad \text{--- (6)}$$

Range equation

G_t and A_e → Ant Parameter.

Q: $G = \frac{4\pi A_e}{\lambda^2}$. the effective area → A_e. Represent R_{max} in terms and

$$S_{min} = \frac{P_t G A_e \sigma}{(4\pi)^2 R^4} \quad \text{--- (5)}$$

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

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

$$G = \frac{4\pi A_e}{\lambda^2} \quad \text{--- (7)}.$$

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

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

Substitute G in R

$$\boxed{R_{max} = \left[\frac{P_t A_e^2 \sigma}{4\pi \lambda^2 S_{min}}\right]} \quad \text{--- (9)}.$$

- Parameters that control radar design except (σ) - target cross section.
- long range desired.
  P_T — ↑large.

radiated energy must be received - narrow beam
→ large ant aperture / sensitive to weak signal.

Problem: the unambiguous range of a radar is 200km. It has a
Q: bandwidth of 1MHz. Find the 1) pulse repitition frequency and
(6) 2) pulse repetition interval (time) 3) rate resolution. range
4) pulse width.

Q: If radar has max range 500km, find the required pulse
(7) rep. freq to obtain unambiguous reception.

Receiver Noise: unwanted EM energy which interfere with the wanted signal detected at receiver.
- within receiver / or through antenna.
- noise-free environment.
- thermal motion of conducts of e^- in receiver i/p.
- magnitude of noise ∝ BW.
- available thermal noise power $= kTB_n$
- Radar receiver - by Superheterodyne receiver BW ≃ IF stage.

BW - integrated BW - B_n

$$\boxed{B_n = \frac{\int_0^\infty |H(f)|^2\, df}{|H(f_0)|^2}}$$

H(F) → freq resp of IF amp

H(F0) ⇒ max freq response

Bn → BW of rectangular filter whose noise power is same as the filter with H(F).

Noise figure

$$= F_n = \frac{N_o}{kT_0 B_n G_a} = \frac{\text{Noise o/p of prac Rx.}}{\text{noise of ideal Rx at } T_0}$$

G_a → Available gain $T_0 = 290K$

$$F_n = \frac{Si/Ni}{So/No}.$$

$$Si = (Ni)\left(\frac{So}{No}\right)Fn$$

$$Ni = KT_0 B_n.$$

$$Si = \left(\frac{KT_0 B_n F_n So}{No}\right).$$

→ Noise Figure has a measure of degradation of SNR as a sig passes through receiver. (NI).

→ the minimum deductable sig = value of the minimum SNR at the o/p of IF amp. i.e; So/No.

→ the min deductable sig is independent of the receiver BW ~~and~~ noise figure.

Integration of Radar Pulses.

no of pulses n_B returned from a point target as the radar antenna scans its BW.

$$n_B = \frac{\theta_B f_p}{\theta_s}.$$

θ_B → anti Beamwidth

θ_s → scanning rate °/sec.

f_p → pulse repetition rate.

↓ bits/sec

pulses/scan.

Summing all the radar echo pulses for the improving detection → integration.

→ either b4 or after and detector

→ n pulses are of same SNR integrated

→ resultant SNR pulse

→ n times of single pulse.

→ same n pulses = integrated by an ideal post detection, resul SNR < n times of single pulse.

- loss in detection → non linear actn of 2^{nd} detectn.
- Post-detectn (easier)

Efficiency of post detection

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

$n E_i(n)$ → integration improvement factor.

radio eqn with n integrated pulse

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

SNR of n equal pulses that are integrated to produce the required prob. of detection for.

Probability of detection / False alarm.

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

radar cross-sectn of target → area intercepting that amount of power which when scattered equally in all directn, produces an echo sig at the radar equal to that from the target.

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

$$\sigma = 4\pi R^2 \frac{[E_r]^2}{[E_i]^2}$$

E_r = ER of echo sig.

E_i → incident E on target

1) Duplexer.
2) Pulse repetitn freq
3) pulse compression.
4) Range eqn. & significance of matched filter
6) freq range radar operatn.
7) applicatns of radar
8) types of radar
9) define gain of an antenna.
10) give data eqn depicting the relatn b/w G and Ae.

Q: ① A radar operates at a prf of 1000Hz with a pulse width of 2μs. and at an avg power of 100W. Find the peak power and duty cycle

Q: ② A radar operates at a peak power of 500KW and a duty cycle of 0.001. Find avg power.

Q: ③ A radar operates at a peak power of 10MW and avg power=100KW prf → 1KHz. Find duty cycle and PRT → (1/prf).

Q: ④ If a pulse radar operates with a pulse width of 2μs and prf of 800Hz. find max. unambiguous range and range resolution.

#CN

Q: ⑤ If a pulse radar operating with a peak power of 1MW has foll. properties:- 1) pulse width → 1.2μs. 2) pulse repetitn interval → 1ms
Find
1) PRf.
2) avege power.
3) duty cycle
4) max range of radar.

Q: ⑥ If a radar receiver has an IF BW of 3MHz and noise figure of 9dB. find min receivable sig.

1) Range = $R_{max} = \frac{c}{2f_p}$

2) Range resolution = $\frac{c \times PW}{2}$

3) Duty cycle = $\frac{P_{av}}{P_{peak}} = PW \times PRF$

⇒ 1) $prf = 1000\,Hz$.

$PW = 2\,\mu s$.

$P_{av} = 100\,W$.

$\frac{100}{P_{peak}} = 2 \times 10^{-6} \times 1000$.

$P_{peak} = \frac{100 \times 10^{5}}{1000 \times 2} \Rightarrow \frac{10 \times 10^{4}}{2} \Rightarrow \underline{50000\,W} \Rightarrow \underline{50\,KW}$ ✓

$DC = 2 \times 10^{-6} \times 1000$.

$= \underline{2 \times 10^{-3}}$ ✓

2) - $P_{peak} = 500\,KW$.

$DC = 0.001$

$P_{av} = 0.001 \times 500 \times 10^{3}$

$= \underline{500\,W}$ ✓

3). $P_{peak} = 10 \times 10^{6}\,W$

$P_{avg} = 100 \times 10^{3}\,W$.

$Prf = 1 \times 10^{3}\,Hz$.

$DC = \frac{100 \times 10^{3}}{10 \times 10^{6}} \Rightarrow \frac{10^{4}}{10^{6}} = \underline{10^{-2}}$ ✓

$PRT = \frac{1}{Prf} = \frac{1}{10^{3}} = \underline{10^{-3}} \Rightarrow \underline{1\,ms}$ ✓

4) $PW = 2 \times 10^{-6}\,s$.

$prf = 800\,Hz \Rightarrow f_p$

range $= \frac{3 \times 10^{8}}{800 \times 2} = \underline{0.1875 \times 10^{6}}$

range res. $= \frac{3 \times 10^{8} \times 2 \times 10^{-6}}{2} \Rightarrow 3 \times 10^{2}$

$\Rightarrow \underline{300\,m}$.

5). $P_{peak} = 1\,MW$

$PW = 1.2 \times 10^{-6}$.

$PRT = 1 \times 10^{-3}$ 1) $PRF = 10^{3} \Rightarrow 1\,KHz$ ✓

2) $P_{avg} = 1.2 \times 10^{-6} \times 10^{3} \times 10^{6}$

$= \underline{1.2\,KW}$ ✓

3) $DC = 1.2 \times 10^{-6} \times 10^{3} \Rightarrow \underline{1.2 \times 10^{-3}}$ ✓

4) Range $= \frac{3 \times 10^{8}}{2 \times 10^{3}} \Rightarrow 1.5 \times 10^{5}\,m \Rightarrow \underline{150\,Km}$

5) range = 200km
BW = 1MHz
prf = ?

$\Delta f_p = \frac{c}{R_{max}}$

$f_p = \frac{c}{2R_{max}} = \frac{3\times10^{8}}{2\times200\times10^3} \Rightarrow \frac{3\times1000}{4} \Rightarrow \underline{\underline{750Hz}}$

$PRT = 1/prf = 1/750 = 0.\underline{\underline{00133}}s$

range resolutn $= \frac{c\times PW}{2}$

4) pulse width.

Parvathy Bab
RA20110040101

7) range $= 500\times10^3 m$
prf = ?

$Range = \frac{c}{2f_p}$

$f_p = \frac{c}{2\,Range} = \frac{3\times10^{8}}{2\times500\times10^3} = \frac{3\times1000}{2\times10} \Rightarrow \underline{\underline{300Hz}}$.

res =

8) BW = 3MHz
noise figure = 9dB

$\boxed{\text{minimum receivable sig} = KTAB(F-1)}$

Radar cross-section of Target

$\sigma = 4\pi R^2 \frac{|E_r|^2}{|E_i|^2}$

σ = area that intercepts a part of
incident at the target, scatters
uniformly in all directions.
– produces echo sig.
= that produced at radar by
real target.

→ depends on the characteristics dimensions of the object compared to wavelength.

→ when λ is large compared to the objects dimensions
↳ Rayleigh Region.

→ proportional to f^4 determined by volume of the scatterer than by its shape.

→ At radar freq — echo signal from rain – rayleigh.

→ At other extreme λ is small compared to obj dimensions →
↳ optical region.

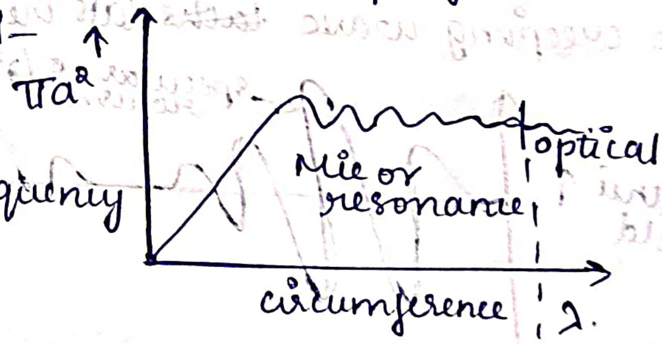
→ Radar scattering from complex object.

→ significant changes in σ when there is change in f or aspect angle at which the object is viewed.

→ affected by shape of the object than its projected area.

→ B/w Rayleigh and optical – Mie radar λ is comparable to obj. dimensions.

→ σ is oscillatory with frequency within this region.



radar cross-section of a simple sphere as a function of circumference measured in wavelength ($2\pi a/\lambda$).

usual radar targets are larger than raindrops. → lowering the radar frequency will not reduce σ of target.

$2\pi a/\lambda$ large → σ approaches optical cross section πa^2.

sphere σ → not aspect sensitive.

→ the sphere cylinder rod type, cone are eg of simple target flat-plate etc.

→ ~~for complex target~~ →

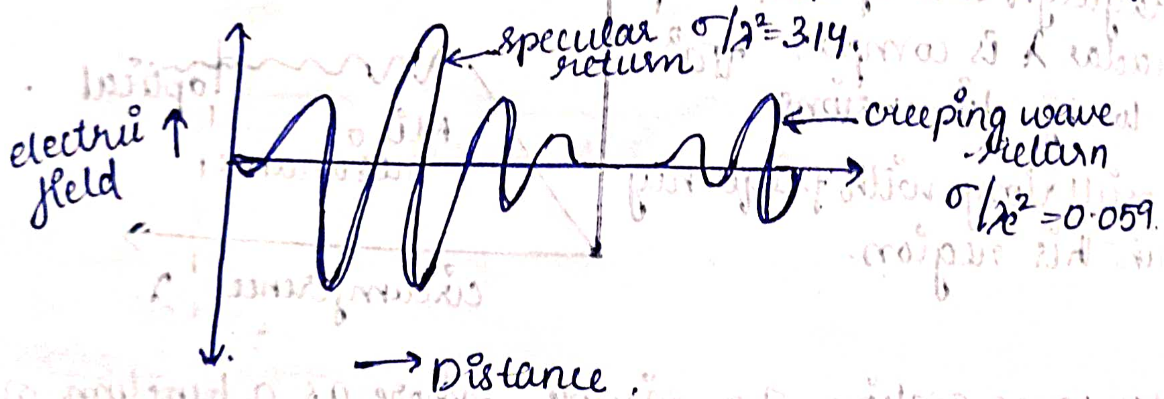
changes in the cross-section occurs with changing frequency bcoz there are 2 waves that interfere constructively and destructively.

i) direct reflection from the front face of the sphere

the other is a ~~peeping~~ creeping wave that travels around the back of sphere and returns to radar where it interferes with reflection from the front of the sphere.

→ the longer the elliptical part around the sphere, greater the loss so the smaller will be the mag of fluctuation with increasing frequency.

→ the creeping wave ~~backs~~ lags the specular return.



Backscatter electric field that would be produced by a short pulse radar that can resolve the specular echo reflected from the forward part of the sphere from creeping wave

creeping wave lags the specular return by the time required to travel 1/2 the circumference of the sphere plus the diameter

Complex Targets

- depends on viewing aspect and frequency.
- variable results — from multiple individual scatterers.
- each individual scatterers — varying amplitude and phase of echo signal
- individual combine — resultant sig.
- relative phase change
→ relative position of the scatterer change with viewing aspect of or change in f

Target → two equal scattering objects
— small spheres, separated
— by one wavelength
— by four wavelength.
→ If cross-section of each of two equal scatterers is σ_0.
resultant

$$\frac{\sigma_r}{\sigma_0} = 2\left[1+\cos\left(\frac{4\pi l}{\lambda}\sin\theta\right)\right].$$

l → separation
θ → viewing angle wrt the normal of the line joining the scatterers

Complex target

σ_r crosssectn varies from minimum 0 to a maximum of 4 times the cross-section σ_0 of individual scatterer.

the target cross section may be computed with the aid of digital comp / experimentally. the complex-target comprises large no of independent objects that scatter energy in all directions.

the amp & phase of the echo sig from the individual scattering obj measured at a radar receiver determines the total cross-section.

As a separatn wavelength b/w the scatterers, the scattering lopsrop became narrower

as it is larger and more in numbers.

- the practical targets are composed of many initial scatterers undergoing diff character

- There maybe interactn b/w individual scatterers as well as mult scattering obj which complicates the cross-sec of characteristics.

Radar cross-section fluctuations

- small change in viewing aspect of radar target → major Δσ
- complex target → no of individual scatterers
- echo from each scattering center
  - amplitude and phase → independent of other scatterers
  - phase of scatterer → changes acc to distance of individual scattering centre from radar.
- all echoes from individual scatterers add vectorally
  → resultant amplitude and phase

N → no of ind scatterers.

$$S_r(t) = \sum_{i=1}^{N} a_i \sin(2\pi f t + \phi_i) \quad i = 1-N.$$

$$= A \sin(2\pi f t + \phi).$$

$$A = \left[\left(\sum_1 a_i \sin\phi_i\right)^2 + \left(\sum a_i \cos\phi_i\right)^2 \right]^{1/2}.$$

a_i → amplitude of i^{th} scatterer.
$\phi_i = 2\pi f T_i$.
T_i – round-trip-time to ith scatterer.
f – radar frequency.
ϕ – arc tan

→ target aspect change relative to radar.
→ change in distances.
T_i → changes phase also changes.

relative phase shift ...
- yield significant change in amp & phase of composite echo'd sig.

Methods to account for radar cs fluctuations:

→ select a small value of σ that has a high prob. of being exceeded all the time.
min detectable sig.
→ employed for finding the MDS SNR when σ is not constant based on Pdfs that determine the fluctuatns.
→ σ and $\sigma + d\sigma$ → (pdf) gives us the prob of value b/w these.
prob. distributive fns.

→ Pdf gives the prob of finding a particular value of σ b/w the values σ and $\sigma + d\sigma$.
→ In additn to the pdf, the correlatn of the cross-section fluctuatns that differ with time must be known.

SWERLING TARGET MODEL.

Calculate detection prob. for 4 diff fluctuatn models of σ.
2 out of 4 assume → fluctuatns are completely correlated during a particular scan but uncorrelated from scan to scan.

→ 2 cases → fluctuatns are more rapid uncorrelated from pulse to pulse.

Case 1: → applicable to targets with many scatterers.
→ echo pulses received from a target on any one scan are of const amp throughout the entire scan but independent from scan to scan — Rayleigh scatterers
→ slow — assumptions → ignores the effect of ant beam shape on echo amplitudes.

Pdf to identify scatterers = $P(\sigma) = \frac{1}{\sigma_{av}} \exp\left[-\frac{\sigma}{\sigma_{av}}\right]$ $\sigma \geq 0$

↳ average cs (cross-sectns) over all values of target fluctuatns.

Case 2:

→ fluctuations are independent from pulse to pulse rather from scan to scan.

→ fast → pdf same as case 1

Case 3:

→ σ assumed constant within a scan independent from scan to scan.

Pdf → $P(\sigma) = \frac{4\sigma}{\sigma_{av}^2} \exp\left(-\frac{2\sigma}{\sigma_{av}}\right)$ $\sigma \geq 0$.

Case 4:

→ pulse to pulse

→ same pdf as case 3

cs σ substituted on radar eqn for these cases — σ_{av}.

SNR needed to achieve a pdf detection without exceeding specified false alarm prob. can be calculated for each model of target.

radar eqn for partially correlated swerling case.

radar eqn w/noise with int. of pulse

$$\boxed{R_{max}^4 = \frac{P_t G A_e \sigma n E_i(n)}{(4\pi)^2 k T_0 B F_n (S/N)_1 (L_f)^{1/n_e}}}$$

L_f → fluctuation loss

n_e → equivalent no of independent samples integrated.

Pulse repetition frequency :—

→ maximum unambiguous range beyond which targets are not expected.

→ max unambiguous range R_{un}

$$T_p = \frac{2R_{un}}{c}$$

→ echoes appear beyond the maximum R_{un} for a large target.

→ echo signals arrive at a time later than ~~prp~~ period (prp)

→ second turn-around / multiple time around echoes.

→ range of unambiguous echoes → error and confusion

→ pulse doppler radar always operate at a prf due to range ambiguities

→ existence of multiple time around echoes cannot be recognized with constant prf.

— distinguished multiple time around varying prf.

Target A → located within R_{un}

B → distance $> R_{un} < 2R_{un}$

C → $> 2R_{un} < 3R_{un}$

→ when the three prf are superimposed on a radar display — ambiguous display (B & C) looks the same from unambiguous echo of A.

→ prf changed continuously

no of separate prf depend on the mult time around targets.

→ ambiguous range can be recognized by Δ prf of the radar sy instead of modulating the prf. to mark successive pulses and to identify mult time around echoes, pulses of diff amp/freq can be used.

→ when prf is changed, the unambiguous echo remains at its true range.
Ambiguous echoes appear at diff. ranges for each prf
The prf is changed pulse to pulse at every ½ beamwidth (θ_B) or on every rotatn of the antenna.

SYSTEM LOSSES:—

loss → reciprocal of efficiency.

* Microwave plumbing loss:
  - → loss in transmission line that connects the antenna, Tx and Rx.
  - → loss due to directional couples, tx line connectors, mirrors of antenna, bends in transmission lines.

* Transmission line loss:
  - → flexible waveguide and co axial lines higher losses
  - → low radar frequency – less to ss
    high radar frequency – attenuation
  - → connectors bending distance b/w Tx and Rx.

* Duplexer loss:
  - → waveguide shutter to protect receiver from HPT.
    insertion loss > 2dB → 2 way loss.

* Antenna loss:
  i) Beam shape loss.
  - → train of pulses returned from a target by a scanning antenna is modulated in amplitude by the shape of antenna beam.
  - → only one out of n pulses has max antenna gain of
  - → peak of antenna beam in the direction of target.
  - → prob of detection have to take account of all train of pulses than constant pulses.

— Scanning loss
— Radome loss.
— phased array loss.

$\boxed{\text{pulses are integrated all with max } \eta.}$

Scanning loss:
When the antenna scans rapidly relative to the roundtrip time of echo sig, the antenna gain in the directn of the target at the transmit side is not the same as that on the receiver side. → additnal loss
⇒ Scanning loss

Phased array loss:
due to the distributn n/w that connects the txd & Rx. of each of the elmts of antenna array.

Radome loss:
loss due to the type of radar & freq used.

Signal Processing loss: Detector Approxn:
→ detecting targets in clutter and in extracting info from radar echo sig will have a loss in the processing.
eg:- non matched filter, hash filter, pulse compression filter.

→ It is const false alarm Rate Loss (CFAR):
• the radar detects threshold is adjusted as a fn of the receiver noise level in order to maintain a CFAR.

→ Quantizatn loss:
• Finite word length (no of bits) and quantizatn noise cause an ↑ in noise power density

Antenna gain.

$$G(\theta,\phi) = \frac{\text{power radiated per unit solid angle in azimuth } (\theta) \text{ and elevation } (\phi)}{\text{power accepted by antenna from its generator}/4\pi}$$

→ Eclipsing loss: echos from multiple time around target arrive back at the radar at the same time of pulse transmitted.

$L_c(m,n) = L_P(m+n)$

Collapsing loss:
→ due to integratn of add noise samples along with sig plus noise pulses which degrades the sigs.
→ ratio of integratn loss (L_i) for $(m+n)$ pulses to the integ loss for n pulses.

Operator losses:
→ operators used for detectn decision
→ should be Δ for every 30 min.

other losses
↳ equipment degradatn
↳ field degradatn.
↳ operator loss.

Radar and Navigational Aids.

INDEX

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Sl. No.	Date	Title	Page No.	Teacher Sign/ Remarks