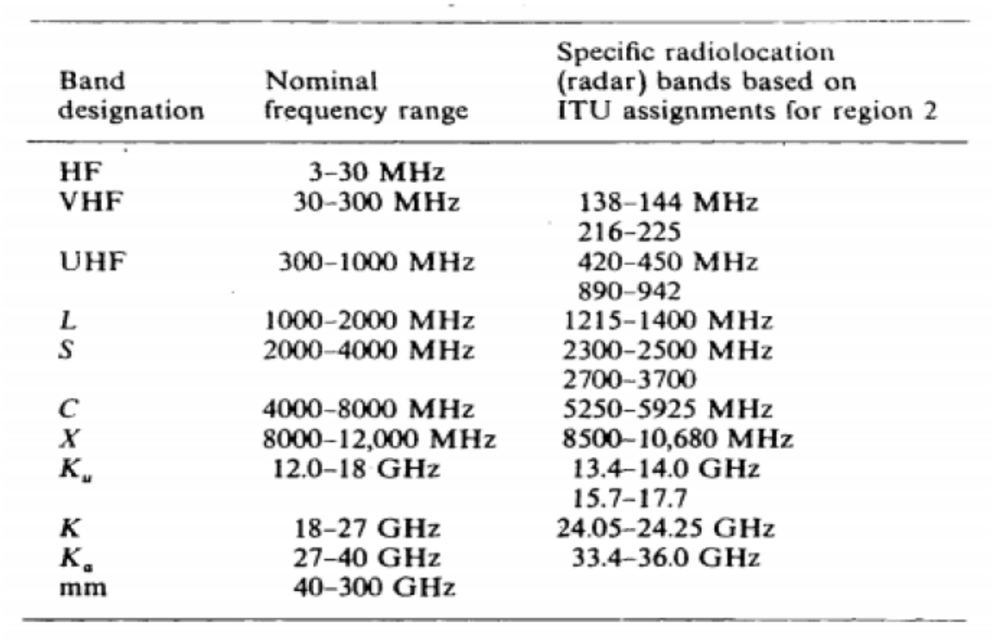
Q.2 a. List out the frequencies used for RADAR and its various applications.

Answer:



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

Applications of Radar:

Radar has been employed on the ground, in the air, on the sea, and in space. Ground-based radar has been applied chiefly to the detection, location, and tracking of aircraft or space targets.

Shipboard radar is used as a navigation aid and safety device to locate buoys, shore lines, and other ships as well as for observing aircraft. Airborne radar may be used to detect other aircraft, ships, or land vehicles, or it may be used for mapping of land, storm avoidance, terrain avoidance, and navigation. In space, radar has assisted in the guidance of spacecraft and for the remote sensing of the land and sea.

The major user of radar, and contributor of the cost of almost all of its development, has been the military: although there have been increasingly important civil applications, chiefly for marine and air navigation. The major areas of radar application, in no particular order of importance, are described below.

Air Traffic Control (ATC): Radars are employed throughout the world for the purpose of safely controlling air traffic en route and in the vicinity of airports. Aircraft and ground vehicular traffic at large airports are monitored by means of high-resolution radar. Radar has been used with GCA (ground-control approach) systems to guide aircraft to a safe landing in bad weather. In addition, the microwave landing system and the widely used ATC radar-beacon system are based in large part on radar technology.

Aircraft Navigation: The weather-avoidance radar used on aircraft to outline regions of precipitation to the pilot is a classical form of radar. Radar is also used for terrain avoidance and terrain following. Although they may not always be thought of as radars, the radio altimeter (either FM/CW or pulse) and the doppler navigator are also radars.

Sometimes ground-mapping radars of moderately high resolution are used for aircraft navigation purposes.

Ship Safety: Radar is used for enhancing the safety of ship travel by warning of potential collision with other ships, and for detecting navigation buoys, especially in poor visibility. In terms of numbers, this is one of the larger applications of radar, but in terms of physical size and cost it is one of the smallest. It has also proven to be one of the most reliable radar systems. Automatic detection and tracking equipments (also called plot extractors) are commercially available for use with such radars for the purpose of collision avoidance. Shore-based radar of moderately high resolution is also used for the surveillance of harbors as an aid to navigation.

Space: Space vehicles have used radar for rendezvous and docking, and for landing on the moon. Some of the largest ground-based radars are for the detection and tracking of satellites. Satellite-borne radars have also been used for remote sensing as mentioned below.

Remote Sensing: All radars are remote sensors; however, as this term is used it implies the sensing of geophysical objects, or the "environment." For some time, radar has been used as a remote sensor of the weather. It was also used in the past to probe the moon and the planets (radar astronomy). The ionospheric sounder, an important adjunct for HF (short wave) communications, is a radar. Remote sensing with radar is also concerned with Earth resources, which includes the measurement and mapping of sea conditions, water resources, ice cover, agriculture, forestry conditions, geological formations, and environmental pollution. The platforms for such radars include satellites as well as aircraft.

Law Enforcement: In addition to the wide use of radar to measure the speed of automobile traffic by highway police, radar has also been employed as a means for the detection of intruders.

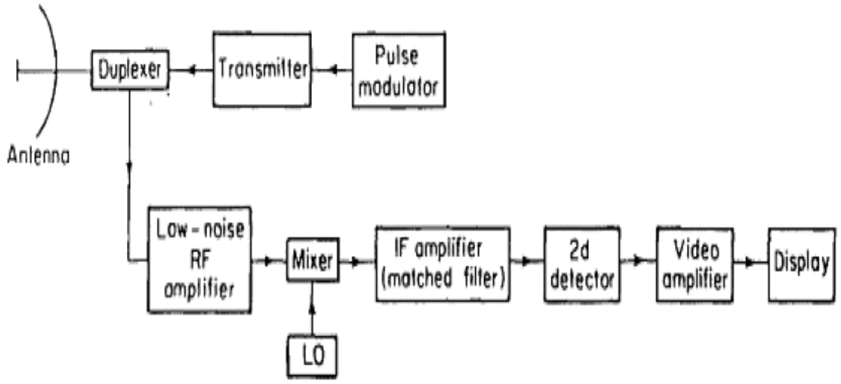
Military: Many of the civilian applications of radar are also employed by the military. The traditional role of radar for military application has been for surveillance, navigation, and for the control and guidance of weapons. It represents, by far, the largest use of radar.

b. Explain the basic principle of radar with a simple sketch. What are various units of distance?

Answer:

Radar Block Diagram and Operation:

The operation of a typical pulse radar may be described with the aid of the block diagram shown in Figure shown below



The transmitter may be an oscillator, such as a magnetron, that is "pulsed" (turned on and on) by the modulator to generate a repetitive train of pulses. The magnetron has probably been the most widely used of the various microwave generators for radar. A typical radar for the detection of aircraft at ranges of 100 or 200 nmi might employ a peak power of the order of a megawatt, an average power of several kilowatts, a pulse width of several microseconds, and a pulse repetition frequency of several hundred pulses per second. The waveform generated by the transmitter travels via a transmission line to the antenna, where it is radiated into space. A single antenna is generally used for both transmitting and receiving. The receiver must be protected from damage caused by the high power of the transmitter. This is the function of the duplexer. The duplexer also serves to channel the returned echo signals to the receiver and not to the transmitter. The duplexer might consist of two gas-discharge devices, one known as a TR (transmit-receive) and the other an ATR (anti-transmit-receive). The TR protects the receiver during transmission and the ATR directs the echo signal to the receiver during reception. Solid-state ferrite circulators and receiver protectors with gas-plasma TR devices and/or diode limiters are also employed as duplexers. The receiver is usually of the superheterodyne type. The first stage might be a low-noise RF amplifier, such as a parametric amplifier or a low-noise transistor. However, it is not always desirable to employ a low-noise first stage in radar. The receiver input can simply be the mixer stage, especially in military radars that must operate in a noisy environment. Although a receiver with a low-noise front-end will be more sensitive, the mixer input can have greater dynamic range, less susceptibility to overload, and less vulnerability to electronic interference.

The mixer and local oscillator (LO) convert the RF signal to an intermediate frequency (IF). A " typical" IF amplifier for an air-surveillance radar might have a center frequency of 30 or 60 MHz and a bandwidth of the order of one megahertz. The IF amplifier should be designed as a notched filter; i.e., its frequency-response function H (f) should maximize the peak-signal-to-mean-noise-power ratio at the output. This occurs when the magnitude of the frequency-response function $|H(f)|$ is equal to the magnitude of the echo signal spectrum $|S(f)|$, and the phase spectrum of the matched filter is the negative of the phase spectrum of the echo signal . In a radar whose signal waveform approximates a rectangular pulse, the conventional IF filter bandpass characteristic approximates a matched filter when the product of the IF bandwidth B and the pulse width τ is of the order of unity, that is, $B\tau \approx 1$.

After maximizing the signal-to-noise ratio in the IF amplifier, the pulse modulation is extracted by the second detector and amplified by the video amplifier to a level where it can be properly displayed, usually on a cathode-ray tube (CRT).

Timing signals are also supplied to the indicator to provide the range zero. Angle information is obtained from the pointing direction of the antenna.

Q.3 a. Derive the maximum range for a radar system from first principles.

Answer:

The radar equation relates the range of a radar to the characteristics of the transmitter, receiver, antenna, target, and environment. It is useful not just as a means for determining the maximum distance from the radar to the target, but it can serve both as a tool for understanding radar operation and as a basis for radar design.

If the power of the radar transmitter is denoted by Pt , and if an isotropic antenna is used (one which radiates uniformly in all directions), the power density (watts per unit area) at a distance R from the radar is equal to the transmitter power divided by the surface area $4\Pi R^2$ of an imaginary sphere of radius R, or

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

Radars employ directive antennas to channel, or direct, the radiated power Pt into some particular direction. The gain G of an antenna is a measure of the increased power radiated in the direction of the target as compared with the power that would have been radiated from an isotropic antenna. It may be defined as the ratio of the maximum radiation intensity from the subject antenna to the radiation intensity from a lossless, isotropic antenna with the same power input. (The radiation intensity is the power radiated per unit solid angle in a given direction.) The power density at the target from an antenna with a transmitting gain G is

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

The target intercepts a portion of the incident power and reradiates it in various directions.

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

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

The radar cross section σ has units of area. It is a characteristic of the particular target and is a measure of its size as seen by the radar. The radar antenna captures a portion of the echo power. If the effective area of the receiving antenna is denoted Ae, the power Pr, received by the radar is

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

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

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

This is the fundamental form of the radar equation. Note that the important antenna parameters are the transmitting gain and the receiving effective area.
Antenna theory gives the relationship between the transmitting gain and the receiving effective area of an antenna as

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

Since radars generally use the same antenna for both transmission and reception, Eq. can be substituted into Eq. above, first for Ae, then for G, to give two other forms of the radar equation

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

b. A pulse radar has peak power 5 kW and uses PRF of 10 KHz. Find the required duty cycle, peak repetition intervals, pulse width to make constant average transmitted power of 1 kW and pulse energy.

Answer:

Duty cycle=average power/peak power=1/5=0.2
PRT=1/PRF=0.1 ms
Pulse width=duty cycle x PRT=0.2 x 0.1 x 10^{-3}=20 µsec.
Pulse energy=peak power x pulse width= 5x 10^3 x 20 x 10^{-6} = 0.1 Joules.

c. A radar operating at 1.5 GHz uses a peak pulse power of 2.5 MW and have a range of 100 nmi for objects whose radar cross-section is $1m^{2.}$. if the minimum receivable power of the receiver is 2 x 10^{-13} W. what is the smallest diameter antenna reflector could have, assuming it to be a full paraboloid with η=0.65.

Answer:

f=1.5 GHz so λ=0.2m.
P_t=2.5 MW, R_{max}=100 nmi=185.2 x 10^3 m
σ=1 m^2 P_{min}=2 x10^{-13} W

$$R_{\max} = \left[\frac{P_t A_e^2 \sigma}{4\pi\lambda^2 P_{\min}}\right]^{1/4} \Rightarrow A_e = \left[\frac{P_{\min} \times 4\pi \times \lambda^2 \times R_{\max}^4}{P_t \sigma}\right]^{1/2} = \left[\frac{2\times 10^{-13} \times 4\pi \times 0.2^2 \times (185.2\times 10^3)^4}{2.5\times 10^6}\right]^{1/2}$$

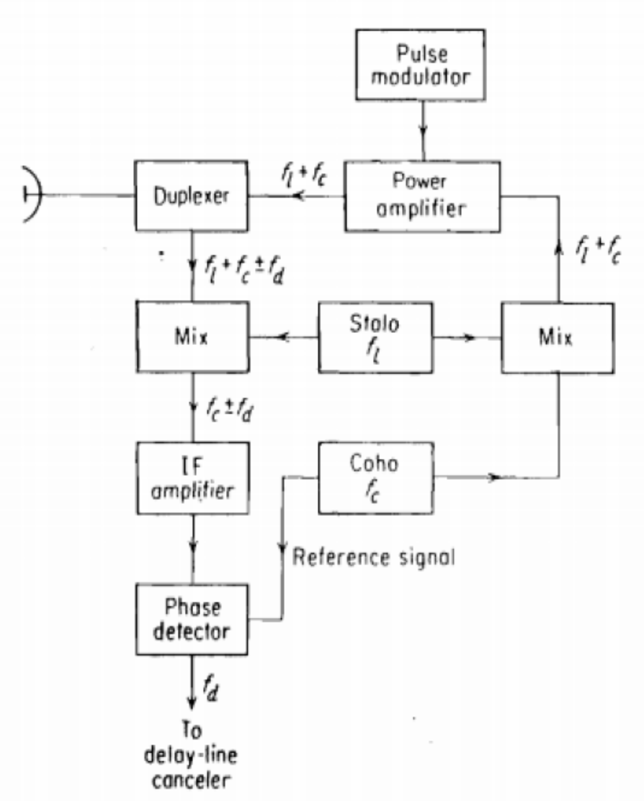
$$A_e = \eta A \Rightarrow A = \frac{6.877}{0.65} = 10.58 \text{ sq.m.}$$

$$\frac{\pi D^2}{4} = 10.58 \Rightarrow D = 3.67m.$$

Q.4 a. Draw the functional block diagram of an MTI radar system and explain its operation. Define the terms range tracking and MTI improvement factor.

Answer:

The radar which uses the concept of Doppler frequency shift for distinguishing desired moving targets from stationary objects i.e., clutter is called as MTI radar (Moving Target Indicator). The block diagram of MTI radar employing a power amplifier is shown in Fig. Below. The significant difference between this MTI configuration and that of Pulse Doppler radar is the manner in which the reference signal is generated. In Fig. 5.1, the coherent reference is supplied by an oscillator called the coho, which stands for coherent oscillator. The coho is a stable oscillator whose frequency is the same as the intermediate frequency used in the receiver. In addition to providing the reference signal, the output of the coho fc is also mixed with the local-oscillator frequency fl. The local oscillator must also be a stable oscillator and is called stalo, for stable local oscillator. The RF echo signal is heterodyned with the stalo signal to produce the IF signal, just as in the conventional superheterodyne receiver. The stalo, coho, and the mixer in which they are combined plus any low-level amplification are called the receiver exciter because of the dual role they serve in both the receiver and the transmitter.



MTI Gain :- MTI gain is the average response of the MTI to targets, defined as the ratio of signal power at the MTI output S_o to that at the input S_i averaged over all target radial velocities of interest :-

$$G_{mti} = \overline{\left(\frac{S_o}{S_i}\right)}$$

because the MTI improvement factor is defined as :-

$$I_m = \frac{\overline{(S_o/C_o)}}{\overline{(S_i/C_i)}}$$

it can also be written as :-

$$I_m = \frac{\overline{(S_o/S_i)}}{\overline{(C_i/C_o)}} = G_{mti}\mathrm{CA}$$

where CA is the clutter attenuation .

The effective MTI gain for targets distributed uniformly over the response is the same as the gain for white noise, and hence there is no gain (or loss) in signal to noise ratio in passage through an MTI canceller. There may be, however, a loss in detection capability caused by introduction of correlation between successive noise samples, loss of quadrature components of both signal and noise, and non uniformity in target response.

MTI improvement -factor :The MTI improvement factor Im is a measure of MTI performance, defined as the signal to clutter ratio of the output of the clutter filter divided by the signal to clutter ratio at the input of the clutter filter, averaged uniformly over all target radial velocities of interest. Equations giving Im for single- , double- and triple delay cancelers as a function of the normalized clutter velocity spread, $z = 2\pi\sigma_v/v_b$, are

$$I_{m1} = \frac{1}{1 - \exp(-z^2/2)} \approx \frac{2}{z^2}$$

$$I_{m2} = \frac{1}{1 - (4/3)\exp(-z^2/2) + (1/3)\exp(-2z^2)} \approx \frac{2}{z^4}$$

$$I_{m3} \approx \frac{4}{3z^6}$$

where σ_v is the standard deviation of the clutter spectrum , v_b is the blind speed of the waveform, and the canceler notch is assumed centered on the clutter spectrum. There is a dependence between improvement factor and other basic parameters describing MTI performance :-

$$I_m = G_{mti}\ \mathrm{CA}$$

$$I_m = D_{xc}\ \mathrm{SCV}$$

$$I_m{}^{-1}{}_{\mathrm{actual}} = I_m{}^{-1}{}_{\mathrm{ideal}}\ \mathrm{CR}^{-1}$$

where G_{mti} is the MTI gain, CA is the clutter attenuation, SCV is the subclutter visibility, D_{xc} is the clutter detectability factor, and CR is the cancellation ratio determined by system instabilities. The ideal improvement factor is computed on the assumption that instabilities have no effect on the clutter returns: - $CR \rightarrow \infty$.
The ratio of MTI improvement factor at a specific Doppler frequency to that averaged over all frequencies is often termed the MTI velocity response.

b. A radar installation used for air traffic control (ATC) is located at an airport and has the following parameters:
S-band surveillance radars

RF frequency	2800 MHz
Transmitter pulse power	500 KW
Prf	430 Hz
Antenna gain	36 dB
Antenna beamwidth in horizontal planets	1.5^o
Antenna rotation rate	6rpm
Receiver bandwidth	1.4 MHz
Total two way RF system losses	10 dB
Pulse width	1µsec
Receive system noise temperature	800 K
Probability of detection	95%
Time between false alarm	one day

(i) Find the number of hits on the targets and estimate the scanning loss.
(ii) Find the probability of false alarm from the receiver bandwidth and false alarm time.
(iii) Find the threshold S/N ratio in dB, for the given probability of detection and false alarm.
(iv) Find the minimum RCS of a target that can be detected at a range of 100 km assuming a constant RCS. Include scanning loss and IF filter mismatch loss of 0.9 dB.

Answer:

i)

The antenna rotation rate of 6 rpm equals one rotation every 10 seconds or 36 degrees/second.
The time to move one beamwidth of 1.5 degrees is 1.5/36 s 41.67 ms.
Prf is 430 Hz, giving pri = 2.33 ms and number of hits per beamwidth = 17.9.
We should use N = 18 hits/beamwidth.
Scanning loss ≈ 2.0 dB

ii)

Time between false alarms is one day = 86,400 seconds

$$P_{fa} = 1 / (B \times T_{fa}) = 1 / (86{,}400 \times 1.4 \times 10^{6}) = 8.3 \times 10^{-12}$$

iii) The probability of false alarm is approximately 10^{-11}.

Entering the vertical axis at $P_d = 0.95$, the intersection of $P_d = 0.95$ and $P_{fa} = 10^{-11}$ is at $(S/N)_T \approx 15.8$ dB

iv)

We know all the parameters of the radar equation except for the radar cross section of the target. The wavelength is easily found by remembering that a 3 GHz radar has a wavelength of 10 cm = 0.1 m. For $f = 2800$ MHz, $\lambda = 0.1 \times 3000 / 2800 = 0.1071$ m or -9.7 dB meter.

Hence:

$$S_{min} = -122.3 \text{ dBW} = P_t + 2\,G + 2\,\lambda + \sigma + 10.6 - 10 - 2 - 0.9 - 33 - 200$$

Rearranging and solving for the target RCS σ in dBmeter^2

$$\sigma = -122.3 - P_t - 2\,G - 2\,\lambda - 10.6 + 10 + 2 + 0.9 + 33 + 200 \text{ dBmeter}^2$$

$$= -122.3 - 57.0 + 72.0 + 19.4 - 10.6 + 10 + 2 + 0.9 + 33 + 200 \text{ dBmeter}^2$$

$$= 3.4 \text{ dBmeter}^2 \text{ or } 2.2 \text{ m}^2.$$

Q.5 a. Derive the expression for frequency response of the matched filter with non-white noise.

Answer:

Matched filter with nonwhite noise: In the derivation of the matched-filter characteristic, the spectrum of the noise accompanying the signal was assumed to be white; that is, it was independent of frequency. If this assumption were not true, the filter which maximizes the output signal-to-noise ratio would not be the same as the matched filter. It has been shown that if the input power spectrum of the interfering noise is given by $[N_i(f)]^2$, the frequency-response function of the filter which maximizes the output signal-to-noise ratio is

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

When the noise is nonwhite, the filter which maximizes the output signal-to-noise ratio is called the NWN (nonwhite noise) matched filter. For white noise $[N_i(f)]^2$ = constant and the NWN matched-filler frequency-response function of Eq. above reduces to that of Eq. discussed earlier in white noise. Equation above can be written as

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

This indicates that the NWN matched filter can be considered as the cascade of two filters. The first filter, with frequency-response function $1/N_i(f)$, acts to make the noise spectrum uniform, or white. It is sometimes called the whitening filter. The second is the matched filter when the input is white noise and a signal whose spectrum is $S(f)/N_i(f)$.

b. Write a note on Neyman-Pearson observer in detection criteria.

Answer: Page Number 284 of Text Book I

Q.6 a. What do you understand by the term clutter? Explain the different types of clutter. Enumerate the properties of Sea and Land clutter.

Answer:

Radar Clutter- Radar returns are produced from nearly all surfaces when illuminated by a radar. Therefore, in competition with the return from an aircraft, there are many sources of unwanted signals. Unwanted signals in a search radar are generally described as noise and clutter. Clutter is the term used and includes ground returns, sea returns, weather, buildings, birds and insects. The definition of clutter depends on the function of the radar. Weather is not clutter in a weather detecting radar.

Since aircraft usually move much faster than weather or surface targets, velocity-sensitive radar can eliminate unwanted clutter from the radar indicator. Radar systems that detect and process only moving targets are called Moving-Target Indicators (MTI).

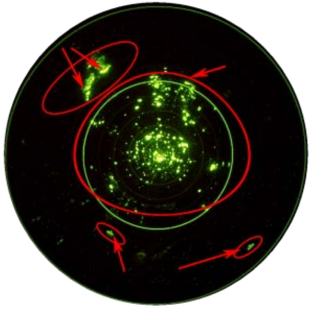


Figure 1: PPI screen of an ATC-radar with targets and clutter

The basic types of clutter can be summarized as follows:

- Surface Clutter – Ground or sea returns are typical surface clutter. Returns from geographical land masses are generally stationary, however, the effect of wind on trees etc means that the target can introduce a Doppler Shift to the radar return. This Doppler shift is an important method of removing unwanted signals in the signal processing part of a radar system. Clutter returned from the sea generally also has movement associated with the waves
- **Volume Clutter** – Weather or chaff are typical volume clutter. In the air, the most significant problem is weather clutter. This can be produced from rain or snow and can have a significant Doppler content.
- **Point Clutter** – Birds, windmills and individual tall buildings are typical point clutter and are not extended in nature. Moving point clutter is sometimes described as angels. Birds and insects produce clutter, which can be very difficult to remove because the characteristics are very much like aircraft.

Clutter can be fluctuating or non-fluctuating. Ground clutter is generally non-fluctuating in nature because the physical features are normally static. On the other hand, weather clutter is mobile under the influence of wind and is generally considered fluctuating in nature.

Clutter can be defined as homogeneous if the density of all the returns is uniform. Most types of surface and volume clutter are analysed on this basis, however, in practice this simplification does not hold good in all cases. Non-homogeneous clutter is non uniform clutter where the amplitude of the clutter varies significantly from cell to cell. Typically non-homogeneous clutter is generated by tall buildings in built up areas.

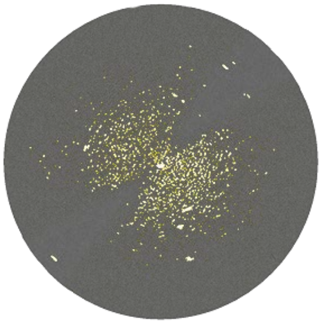


Figure 2: Sea-Clutter on a PPI-Scope

Sea-clutter are disturbing radar-echoes of sea wave crests. This clutter gets also a Doppler- speed by the wind. This means, the scenario „moves away”, i.e. changes with time, while for ground clutter it stays the same. Therefore, in practice, Sea-clutter is very difficult to control without some loss in detection.

Sea-Clutter can be seen here in the picture. The wind comes either from about 310° (NO) or from the opposite direction. (Unfortunately, whether the Doppler frequency is positive or negative cannot be recognized on the PPI-Scope.)

But this region, in which the radial speed of the waves is very small, is „cleaned” by the MTI system very clearly.

This method be left of the time in which an operator or „radio-locator” still sat in front of the PPI-Scope. This is only used at the most today, if all other MTI-devices have failed: A graphic mapping of the clutter zone around a radar site, the operator has to remember this map to still locate the target inside the clutter zone perhaps anyway.

However, this cluttermap can be managed also electronically. The values of the echoes are stored as a data word for every bearing angle and every rangecell there. Only if the data word has changed fundamentally, the echo-blip is shown on the screen.

b. Derive the equation for Surface-Clutter Radar.

Answer: Page Number 404-406 of Text Book I

Q.7 a. A phased array antenna has a square aperture with dimensions 2.72m x 2.72m. the sides of the square are horizontal and vertical. The antenna operates at a frequency of 5.5 GHz. Each radiating element in the array has its own transmitter and receiver, and the element spacing is 0.6λ.

(i) How many elements are there in the array?

(ii) What is the gain of the antenna when the beam is broadside to the array face? Assume that the aperture efficiency of the array antenna is 60%.

(iii) What is the maximum angle to which the beam can be scanned in the horizontal or vertical plane before a grating lobe appears in the horizontal or vertical direction?

Answer:

i)

Answer: At 5.5 GHz, the wavelength is 0.0545 m. Hence each side of the array is 50 wavelengths. With spacing between elements of 0.6 wavelengths, N = 50/0.6 = 83 elements. For a square array, the total number of elements is 6889.

ii)

$$G = \eta_A \times 4\pi A / \lambda^2 = 0.6 \times 4\pi \times 2500 = 18{,}850 \text{ or } 42.8 \text{ dB}$$

iii)

Answer: Grating lobes appear at $\pm\theta_g$ when the beam is steered away from broadside to an angle θ_o according to the equation

$$\sin\theta_g - \sin\theta_o = \pm n\lambda / d$$

Taking n = +1 and an element spacing of 0.6 λ, a grating lobe appears at -90° when the beam is steered to an angle given by

$$\sin\theta_g = -1 = \lambda / 0.6\lambda + \sin\theta_o$$

or $\sin\theta_o = 1.667 - 1 = 0.667$

Hence $\theta_o = 41.8^o$

There are large impedance changes looking into the array when grating lobes appear, so the practical scan limit for an active array with 0.6 wavelength element spacing is about 35°.

b. Describe briefly the two different types of phased-array radar. State their functions.

Answer:

Phased Array Antenna-

A phased array antenna is composed of lots of radiating elements each with a phase shifter. Beams are formed by shifting the phase of the signal emitted from each radiating element, to provide constructive/destructive interference so as to steer the beams in the desired direction.

In the figure 1 (left) both radiating elements are fed with the same phase. The signal is amplified by constructive interference in the main direction. The beam sharpness is improved by the destructive interference.

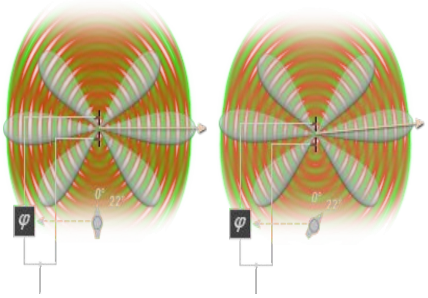


Figure 1: left: two antenna elements, fed with the same phase, right: two antenna elements, fed with different phase shift

In the figure 1 (right), the signal is emitted by the lower radiating element with a phase shift of 22 degrees earlier than of the upper radiating element. Because of this the main direction of the emitted sum-signal is moved upwards.

(Note: Radiating elements have been used without reflector in the figure. Therefore the back lobe of the shown antenna diagrams is just as large as the main lobe.)

The main beam always points in the direction of the increasing phase shift. Well, if the signal to be radiated is delivered through an electronic phase shifter giving a continuous phase shift now, the beam direction will be electronically adjustable. However, this cannot be extended unlimitedly. The highest value, which can be achieved for the Field of View (FOV) of a phased array antenna is 120° (60° left and 60° right). With the sine theorem the necessary phase moving can be calculated.

The following figure graphically shows the matrix of radiating elements. Arbitrary antenna constructions can be used as a spotlight in an antenna field. For a phased array antenna is decisive that the single radiating elements are steered for with a regular phase moving and the main direction of the beam therefore is changed. E.g. the antenna of the RRP 117 consists of 1584 radiating elements arranged in analogue beamforming architecture. More sophisticated radar sets use the benefits of a Digital Beam forming architecture.

Advantages	**Disadvantages**
high gain width los side lobes Ability to permit the beam to jump from one target to the next in a few microseconds Ability to provide an agile beam under computer control arbitrarily modes of surveillance and tracking free eligible Dwell Time multifunction operation by emitting several beams simultaneously Fault of single components reduces the capability and beam sharpness, but the system remains operational	the coverage is limited to a 120 degree sector in azimuth and elevation deformation of the beamwhile the deflection low frequency agility very complex structure (processor, phase shifters) still high costs

Q.8 a. State the factors influence the bandwidth of radar receiver. Write down the advantages of large bandwidth.

Answer:

Receivers Bandwidth

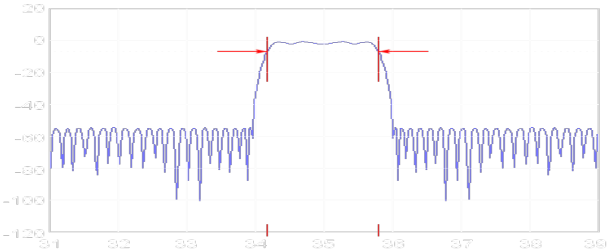


Figure 1: A graph of a bandpass filter's gain magnitude, illustrating the concept of -3 dB (or half-power) bandwidth

Bandwidth- Bandwidth B, BW or Δf is the difference between the upper and lower cut-off frequencies of a radar receiver, and is typically measured in hertz. In case of a baseband channel or video signal, the bandwidth is equal to its upper cut-off frequency. In a Radar receiver the bandwidth is mostly determined by the IF filter stages. The receiver must be able to process the signal bandwidth of the backscattered pulse.

The wider the bandwidth, the greater the degree of noise that will be input to the receiver. Since noise exists at all frequencies, the broader the frequency range to which the receiver bandpass filters are tuned, then the higher the intensity level of the noise and the lower the signal-to-noise ratio, and so the receivers sensibility.

The bandwidth is roughly proportional to the amount of information carried by the signal. To detect a rectangle pulse with the Fast Fourier Transformation (FFT) the bandwidth of the receiver is equal to the highest sine wave frequency component that is significant. The higher the receivers bandwidth, the slower is the rise time of the edges of the rectangle signal.

Generally the necessary bandwidth B of a pulse in form of a half wave sine signal of duration τ is:

$$B = 1/\tau \qquad (1)$$

The influence of the Doppler Effect will change the signal duration and bandwidth of the backscattered pulse. To obtain the Doppler information the installed bandwidth of the radar receiver must be higher than the signal bandwidth of the transmitted pulse.

In a radar system using the intra-pulse modulation of the transmitted pulse, the necessary bandwidth of a radar receiver is much higher than the reciprocal of their pulse width. In this case the necessary bandwidth of a radar receiver depends on the internal modulation of the signal, the compressed pulse width and a weighting function, to achieve the required time sidelobe level. A maximum practical bandwidth of approximately 200 MHz is possible using current techniques. High-end receivers can have a *tunable bandwidth*.

Time Bandwidth Product-A common figure which characterises pulse compression devices is a time bandwidth product expressed as $\tau \cdot B$ (in µs·MHz). Values of $\tau \cdot B$ between 5 and 1000 can be achieved in some radar systems. For low values of $\tau \cdot B$, e.g. between 5 and 15, there are developed techniques which allow sidelobe suppression exceeding 35 dB, which is considerably better than expected. For $\tau \cdot B$ between 15 and 500 as used in high end radar receivers, sidelobe levels can vary from 35dB to 45dB, depending on e.g the Doppler shift, mismatch loss trade-off, and the selected value of the Intermediate Frequency (IF).

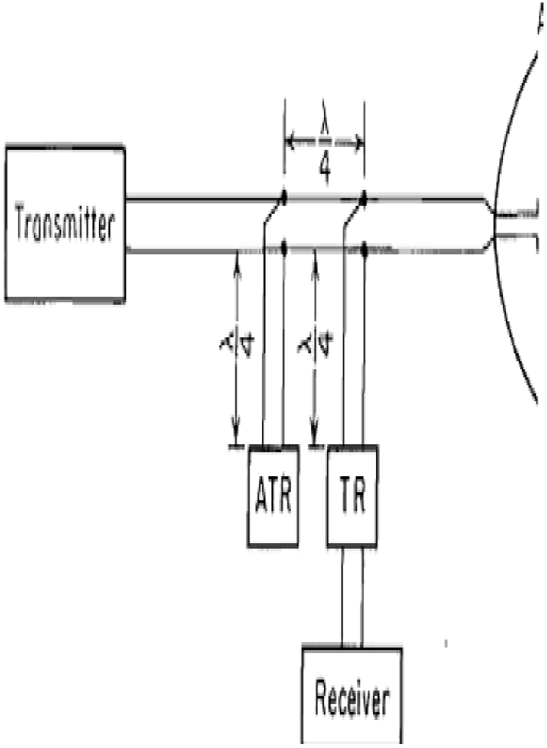
A high Time Bandwidth Product of up to 1000 is usable for a high range resolution and an additional measuring of an altitude based on the time separation between the direct signal and the surface-reflected signal (Multipath Height Finding Method).

b. Explain the following:
(i) Balanced type duplexer
(ii) Branch type duplexer

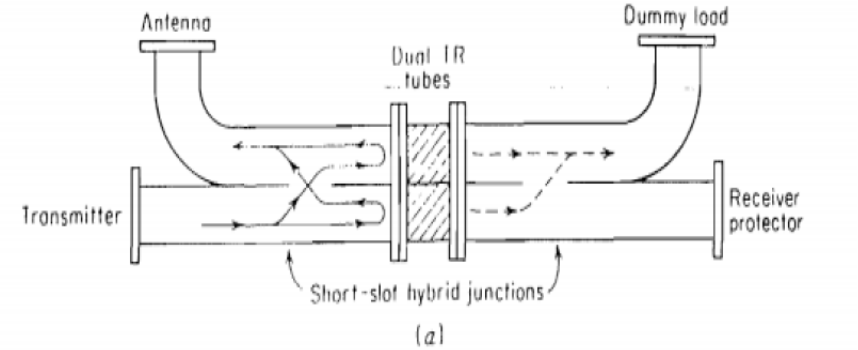
Answer:

(i) Branch-type duplexers: The branch-type duplexer, diagrammed in Figure below was one of the earliest duplexer configurations employed. It consists of a TR (transmit-receive) switch and an ATR (anti-transmit receive) switch, both of which are gas-discharge tubes. When the transmitter is turned on, the TR and the ATR tubes ionize; that is, they break down, or fire. The TR in the fired condition acts as a short circuit to prevent transmitter power from entering the receiver. Since the TR is located a quarter wavelength from the main transmission line, it appears as a short circuit at the receiver but as an open circuit at the transmission line so that it does not impede the flow of transmitter power. Since the ATR is displaced a quarter wavelength from the main transmission line, the short circuit it produces during the fired condition appears as an open circuit on the transmission line and thus has no effect on transmission. During reception, the transmitter is off and neither the TR nor the ATR is fired. The open circuit of the ATR, being a quarter wave from the transmission line, appears as a short circuit across the line. Since this short circuit is located a quarter wave from the receiver branchline, the transmitter is effectively disconnected from the line and the echo signal power is directed to the receiver. The diagram of Figure shown below is a parallel configuration. Series or series-parallel configurations are possible.

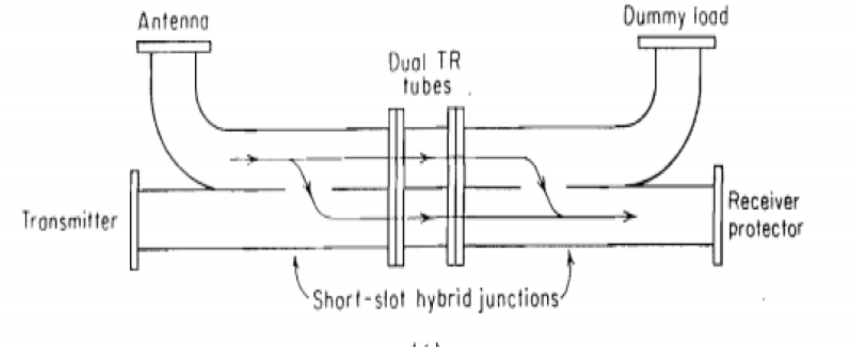
The branch-type duplexer is of limited bandwidth and power handling capability, and has generally been replaced by the balanced duplexer and other protection devices. It is used, inspite of these limitations, in some low-cost radars.



(ii) Balanced duplexer: The balanced duplexer, figure shown below is based on the short-slot hybrid junction which consists of two sections of waveguides joined along one of their narrow walls with a slot cut in the common narrow wall to provide coupling between the two. The short-slot hybrid may be considered as a broadband directional coupler with a coupling ratio of 3 dB. In the transmit condition power is divided equally into each waveguide by the first short slot hybrid junction. Both TR tubes break down and reflect the incident power out the antenna arm as shown



(a)



(b)

The short-slot hybrid has the property that each time the energy passes through the slot in either direction, its phase is advanced 90° . Therefore, the energy must travel as indicated by the solid lines. Any energy which leaks through the TR tubes (shown by the dashed lines) is directed to the arm with the matched dummy load and not to the receiver, In addition to the attenuation provided by the TR tubes, the hybrid junctions provide an additional 20 to 30 dB of isolation

On reception the TR tubes are unfired and the echo signals pass through the duplexer and into the receiver as shown in b. The power splits equally at the first junction and because of the 90° phase advance on passing through the slot, the energy recombines in the receiving arm and not in the dummy-load arm.

The power-handling capability of the balanced duplexer is inherently greater than that of the branch-type duplexer and it has wide bandwidth, over ten percent with proper design. A receiver protector is usually inserted between the duplexer and the receiver for added protection.

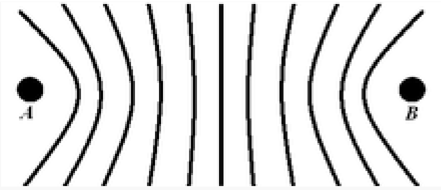
Q.9 a. Write a short note on LORAN-A and LORAN-C.

Answer:

LORAN (**LO**ng **RA**nge **N**avigation) is a terrestrial radio navigation system which enables ships and aircraft to determine their position and speed from low frequency radio signals transmitted by fixed land based radio beacons, using a receiver unit.

The most recent version of LORAN in use is LORAN-C, which operates in the low frequency (LF) portion of the radio spectrum from 90 to 110 kHz. Many nations have used the system, including the United States, Japan, and several European countries. Russia uses a nearly identical system in the same frequency range, called CHAYKA.

Principle



A crude diagram of the LORAN principle—the difference between the time of reception of synchronized signals from radio stations A and B is constant along each hyperbolic curve; when demarcated on a map, such curves are known as "TD lines". "TD" stands for "Time Difference".

The navigational method provided by LORAN is based on measuring the time difference between the receipt of signals from a pair of radio transmitters.[6] A given constant time difference between the signals from the two stations can be represented by a hyperbolic line of position (LOP).

If the positions of the two synchronized stations are known, then the position of the receiver can be determined as being somewhere on a particular hyperbolic curve where the time difference between the received signals is constant. In ideal conditions, this is proportionally equivalent to the difference of the distances from the receiver to each of the two stations.

So a LORAN receiver which only receives two LORAN stations cannot fully fix its position—it only narrows it down to being somewhere on a curved line. Therefore the receiver must receive and calculate the time difference between a second pair of stations. This allows to be calculated a second hyperbolic line on which the receiver is located. Where these two lines cross is the location of the receiver.

In practice, one of the stations in the second pair also may be—and frequently is—in the first pair. This means signals must be received from at least three LORAN transmitters to pinpoint the receiver's location. By determining the intersection of the two hyperbolic curves identified by this method, a geographic fix can be determined.

LORAN-A was a less accurate system operating in the upper medium wave frequency band prior to deployment of the more accurate LORAN-C system.[10] For LORAN-A the transmission frequencies 1750 kHz, 1850 kHz, 1900 kHz and 1950 kHz were used, shared with the 1800–2000 kHz amateur 160-meter band. LORAN-A continued in operation partly due to the economy of the receivers and widespread use in civilian recreational and commercial navigation. LORAN-B was a phase comparison variation of LORAN-A while LORAN-D was a short-range tactical system designed for USAF bombers. The unofficial "LORAN-F" was a drone control system. None of these went much beyond the experimental stage. An external link to them is listed below.

LORAN-A was used in the Vietnam War for navigation by large United States aircraft (C-124, C-130, C-97, C-123, HU-16, etc.). A common airborne receiver of that era was the R-65/APN-9 which combined the receiver and cathode ray tube (CRT) indicator into a single relatively lightweight unit replacing the two larger, separate receiver and indicator units which composed the predecessor APN-4 system. The APN-9 and APN-4 systems found wide post–World War II use on fishing vessels in the U.S. They were cheap, accurate and plentiful. The main drawback for use on boats was their need for aircraft power, 115 VAC at 400 Hz. This was solved initially by the use of rotary converters, typically 28 VDC input and 115 VAC output at 400 Hz. The inverters were large, noisy and required significant power. In the 1960s, several firms such as Topaz and Linear Systems marketed solid state inverters specifically designed for these surplus LORAN-A sets. The availability of solid state inverters that used 12 VDC input opened up the surplus LORAN-A sets for use on much smaller vessels which typically did not have the 24-28 VDC systems found on larger vessels. The solid state inverters were very power efficient and widely replaced the more trouble prone rotary inverters.

LORAN-A saved many lives by allowing offshore boats in distress to give accurate position reports. It also guided many boats whose owners could not afford radar safely into fog bound harbors or around treacherous offshore reefs. The low price of surplus LORAN-A receivers (often under $150) meant that owners of many small fishing vessels could afford this equipment, thus greatly enhancing safety. Surplus LORAN-A equipment, which was common on commercial fishing boats, was rarely seen on yachts. The unrefined cosmetic appearance of the surplus equipment was probably a deciding factor.

b. A monopulse tracking radar has a tracking slope of 1.0 volts per degree close to the antenna boresight. Within 0.1 degree of the boresight the antenna gain in the sum channel can be assumed to be constant 1.0 volts relative to the difference channel output.

(i) What is the output of the azimuth difference channel, in volts and in dB, relative to 1.0 volts in the sum channel when a target is 0.008 degrees away from the antenna axis in the horizontal plane?

(ii) The sum channel of the receiver has a bandwidth of 1.5 MHz. The S/N in the difference channel must be 30 dB when a target is 0.02 degrees off axis. What bandwidth is required in the difference channel to achieve this specification?

Answer:

a)

The tracking signal output is given by $V_t = 1.0 \times angle = 0.08$ *volts*

Assuming $V_t^2 \propto P_t$ *this corresponds to* -21.9 *dB.*

b)

With the target 0.02 degrees off the antenna axis $V_t = 0.02$ *volts.*

Assuming $V_t^2 \propto P_t$ *this is a signal at* $20 \log 0.02 = -34.0$ *dB*

TEXT BOOKS

1. Introduction to Radar Systems, Merrill I. Skolnik, 3e, TMH, 2001
2. Electronic and Radio Engineering, F.E. Terman, McGraw Hill Publications.