RADAR & NAVIGATION AIDS

By Prof. Hitesh Dholakiya
Engineering Funda YouTube Channel

SSASIT, SURAT

Course Content

Principles of Radar: Introduction, The simple form of Radar Equation, Radar Block diagram and Operation, Radar Frequencies, millimetre and submillimeter waves, Applications of Radar.

Radar Equation: Prediction of Range Performance, Minimum Detectable Signal, Receiver Noise, Signal to Noise Ratio, Matched filter impulse response, Integration of radar Pulses, Radar Cross Section of Targets, Cross section Fluctuations, Radar Clutter-surface clutter, sea clutter and Land clutter, weather clutter, Transmitter Power, Pulse Repetition Frequency and Range ambiguities, Antenna Parameters, system losses, propagation effects, other considerations

Antennas for Radar & Navigation: Introduction, Fundamental Antenna Concept, Reflector Antennas, phased Array antennas, Loop Antenna

CW and FM Radar: The Doppler effect, CW radar, FMCW radar, Airborne Doppler Navigation, Multiple Frequency CW radar

MTI and Pulse Doppler Radar: Introduction, Delay line Cancellers, Multiple or staggered Pulse Repetition Frequencies, Range gated Doppler Filters, Block Diagram of Digital Signal Processor, Example of MTI radar Processor, , Pulse Doppler Radar, Non coherent MTI ,MTI from moving platform, Other types of MTI, Airborne radar.

Tracking and Imaging Radar: Tracking with radar, Monopulse tracking, conical scan and sequential lobbing, Low angle tracking, Air Surveillance Radar, Introduction to Synthetic aperture radar (SAR).

Navigation: Introduction, Four Methods of Navigation

Radio Direction Findings: Loop Antenna, Loop input circuits, aural null direction finder, Goniometer, Errors in Direction Finding, Adcock Direction Finder, Its advantages over loop antenna, Direction Finding at very high frequency, Automatic Direction Finder, Range and Accuracy of Direction Finders

Radio Ranges: LF/MF Four course Radio Range, VHF Omnidirectional Range, and VOR receiving Equipment, Range and Accuracy of VOR.

Hyperbolic Systems of Navigation: LORAN, DECCA navigation system

Aids to approach and Landing: Instrument Landing System, Ground controlled Approach System, Microwave landing system, Distance Measuring Equipment, TACAN,

Modern Navigation : Doppler navigation-Doppler Effect, New configuration, Doppler frequency equations, Track stabilization, Doppler navigation system, GPS principle of operation, Position location determination, principle of GPS receiver.

CHAPTER 1 PRINCIPLES OF RADAR

Introduction

- Radar is an acronym for **Radio Detection and Ranging.**
- The term “radio” refers to the use of electromagnetic waves with wavelength in so called radio wave portion of the spectrum, which covers a wide range from 10^4 Km to 1 cm.
- It is a system used to detect, range (determine the distance) and map objects such as aircraft and rain.
- Strong radio waves are transmitted, and a receiver listen for reflected echoes.
- By analysing the reflected signal, the reflector can be located, and sometimes identified.
- Although the amount of returned is tiny, radio signal can easily be detected and amplified.
- It can operate in darkness, haze, fog, rain and show, it has ability to measure distance with high accuracy in all-weather conditions.
- The electronics principal on which radar operates is very similar to the principle of sound wave reflection.
- If you shout in the direction of sound-reflecting object (like a rocky canon or cave), you will hear an echo.
- If you know the speed of sound in air, you can estimate the distance and general direction of the object.
- The time required for a return echo can roughly converted in to distance if the speed of sound is known.
- Radar uses electromagnetic energy pulses in the same way, as shown in figure 1.1.

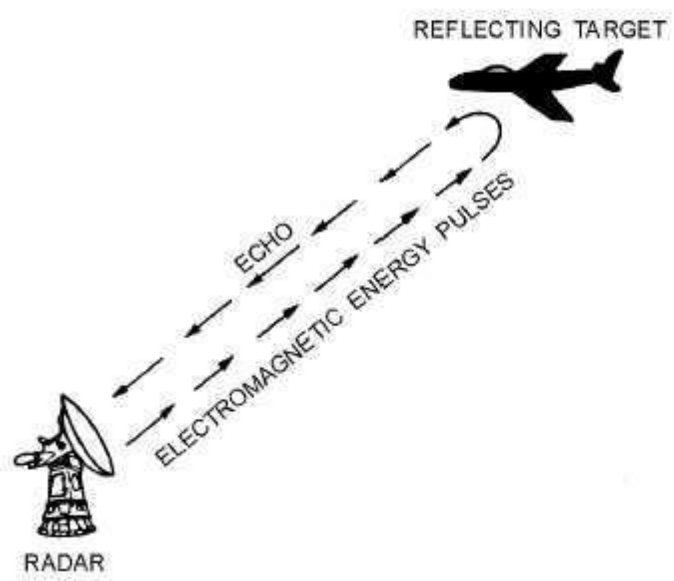


Figure 1.1 RADAR Principle

- The radio frequency energy is transmitted to and reflects from the reflecting object.
- A small portion of the energy s reflected and return to the radar set. This returned energy is called **ECHO**.

Range to a Target

- The most common radar waveform is a train of narrow, rectangular-shape pulses modulating a sine wave carrier. The distance, or range, to the target is determined by measuring the time T_R taken by the pulse to travel to the target and return. Since electromagnetic energy propagates at the speed of light c = 3 x 10^8 m/s, the range R is;

$$\mathbf{R = cT_R / 2}$$

- The factor 2 appears in the denominator because of the two-way propagation of radar. with the range in kilometres or nautical miles, and TR in microseconds, Eq. above becomes;

$$\mathbf{R\ (Km) = 0.15\ T_R\ (us)\ or\ R\ (nmi) = 0.081\ T_R\ (us)}$$

Maximum Unambiguous Range

- Once the transmitted pulse is emitted by the radar, a sufficient length of time must elapse to allow any echo signals to return and be detected before the next pulse may be transmitted.
- Therefore the rate at which the pulses may be transmitted is determined by the longest range at which targets are expected.
- If the pulse repetition frequency is too high, echo signals from some targets might arrive after the transmission of the next pulse, and ambiguities in measuring range might result.
- Echoes that arrive after the transmission of the next pulse are called second-time-around or multiple-time-around echoes. Such an echo would appear to be at a much shorter range than the actual and could be misleading if it were not known to be a second time around echo.
- The range beyond which targets appear as second-time-around echoes is called the **maximum unambiguous range** and is given by;

$$\mathbf{R_{unb} = cT_P / 2 = c/2f_p}$$

- Where fp = pulse repetition frequency, in Hz. A plot of the maximum unambiguous range as a function of pulse repetition frequency is shown in Fig. 1.2.

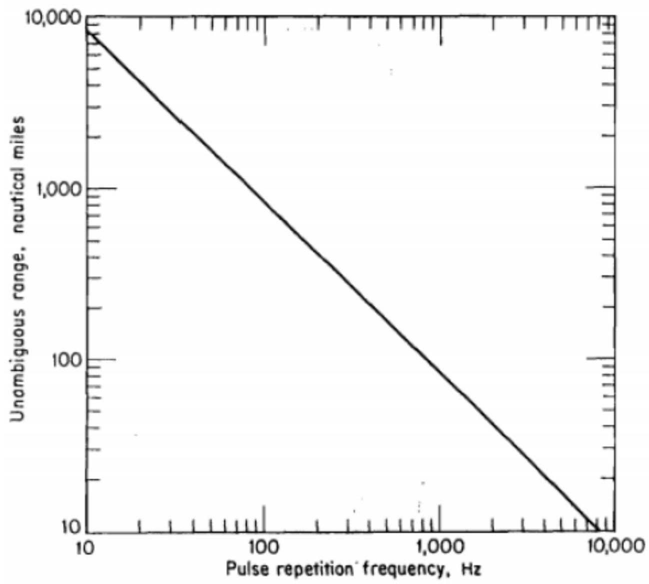


Figure 1.2 Maximum unambiguous range R_{unb} as function of f_p

Radar Frequencies

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

Figure 1.3 IEEE Standard RADAR Frequencies

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.
- **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 equipment's (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 harbours 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.
- **Radar Altimeter:** it measure an aircraft's true height above ground.

Radar Range Equation

- 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

  Power density at range R from an isotropic antenna = $P_t / 4\Pi R^2$
- 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;

  Power density at range R from a directive antenna = $P_tG / 4\Pi R^2$
- 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.

Reradiated power density back at the radar = $(P_t G / 4\Pi R^2) (\sigma / 4\Pi R^2)$

- 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 A_e, the power P_r, received by the radar is;

$$P_r = (P_t G / 4\Pi R^2) (\sigma / 4\Pi R^2) A_e$$

- The maximum radar range R_{max} 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 S_{mi}n,
- Therefore;

$$R_{max} = P_t G \sigma A_e / (4\Pi)^2 S_{min}$$

- 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;

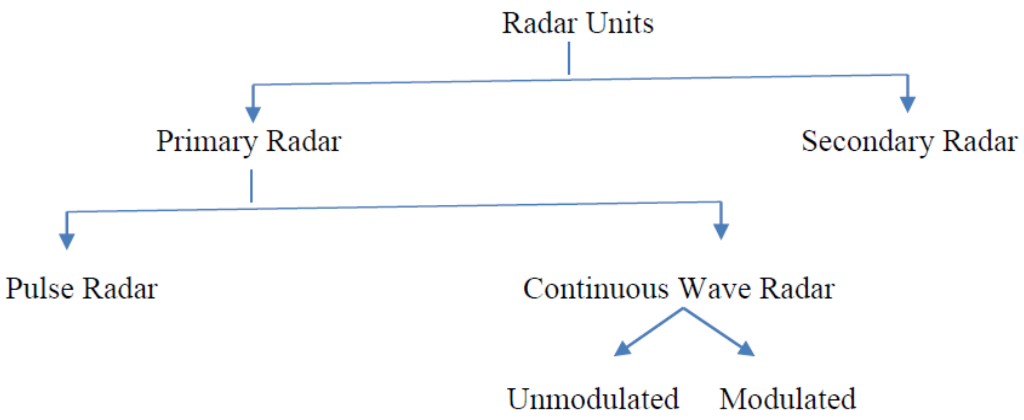
$$G = 4\Pi A_e / \lambda^2$$

- 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;

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

Different Types of Radar

- Radar systems may be divided into types based on the designed use.
- Some commonly use radar systems are;
    1. Air defense radars
    2. Air traffic control radar
    3. Fire control radar
    4. Speed gauges
    5. Mortar locating radar
    6. Radar satellites
    7. Weather radar
    8. Ground penetrating radar etc.
- **Radars are classifies as below**;



- **Primary Radar**
- A primary radar transmits high-frequency signal which are reflected at targets. The echoes are received and evaluated. This means, unlike secondary radar units a primary radar unit receive its own emitted signal as an echoes again.
- **Secondary Radar**
- At these radar units the airplane must have a transponder on board and receives an encoded signal of the secondary radar unit. An active also encoded response signal, which is returned to the radar unit then is generated in the transponder. eg. IFF (Identification of Friend and Foe).
- **Pulse Radar**
- Pulse radar units transmit a high-frequency impulsive signal of high power. After this a longer break in which the echoes can be received follows before a new transmitted signal s sent out. Direction, distance and sometimes altitude also can be determined.
- **Continuous Wave Radar**
- Continuous-wave radar is a type of radar system where a known stable frequency continuous-wave radio energy is transmitted and then received from any reflecting objects. Continuous-wave (CW) radar uses Doppler, which renders the radar immune to interference from large stationary objects and slow moving clutter. CW radar systems are used at both ends of the range spectrum.
- **Unmodulated CW Radar**
- The transmitted signal of these equipment is constant in amplitude and frequency. These equipment's are specialized in speed measuring. Distance cannot be measured. eg. It is used as a speed gauge of the police.
- **Modulated Radar**
- Frequency-modulated continuous-wave radar (FM-CW) – also called continuous-wave frequency-modulated (CWFM) radar – is a short-range measuring radar set capable of determining distance. This increases reliability by providing distance measurement along with speed measurement, which is essential when there is more than one source of reflection arriving at the radar antenna. This kind of radar is often used as "radar altimeter" to measure the exact height during the landing procedure of aircraft. It is also used as early-warning radar, wave radar, and proximity sensors. Doppler shift is not always required for detection when FM is used.
- In this system the transmitted signal of a known stable frequency continuous wave varies up and down in frequency over a fixed period of time by a modulating signal. Frequency deviation between the receive signal and the transmit signal increases with delay, and hence with distance. This smears out, or blurs, the Doppler signal. Echoes from a target are then mixed with the transmitted signal to produce a beat signal which will give the distance of the target after demodulation

Radar Block Diagram

❖ The operation of a typical pulse radar may be described with the aid of the block diagram shown in Fig.3.1.

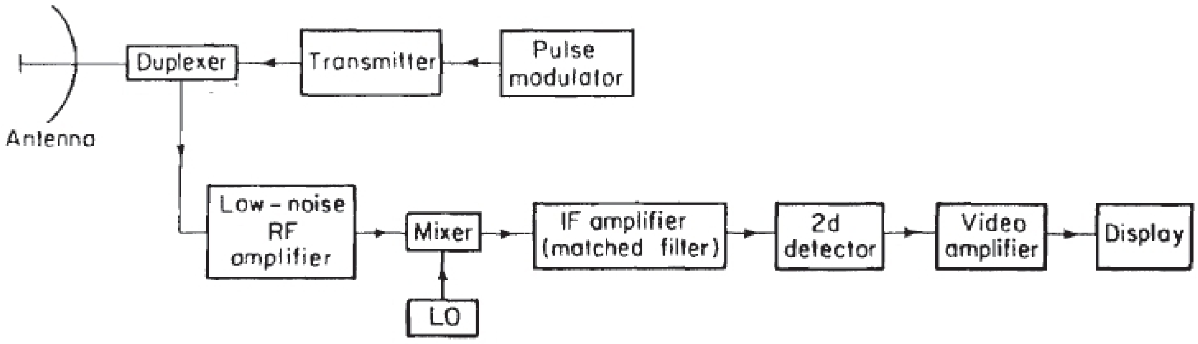


Figure 3.1. Block diagram of simple pulse radar

❖ **Transmitter**

❖ 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.

❖ **Pulse Modulator**

❖ The radar modulator is a device, which provides the high power to the transmitter tube to transmit during transmission period. It makes the transmitting tube ON and OFF to generate the desired waveform. Modulator allows the storing the energy in a capacitor bank during rest time.

❖ The stored energy then can be put into the pulse when transmitted. It provides rectangular voltage pulses which act as the supply voltage to the output tube such as magnetron, thus switching it ON and OFF as required.

❖ **Duplexer**

❖ 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.

❖ **Antenna**

❖ The antenna takes the radar pulse from the transmitter and puts it into the air. Furthermore, the antenna must focus the energy into a well-defined beam which increase the power and permits a determination of the direction of the target.

❖ **Receiver**

❖ The receiver is usually of the super-heterodyne type whose function is to detect the desired signal in the presence of noise, interference and clutter. The receiver in pulsed radar consist of low noise RF amplifier, mixer, local oscillator, IF amplifier, detector, video amplifier and radar display.

- **Low Noise RF Amplifier**
- Low noise amplifier is the first stage of the receiver. It is low noise transistor amplifier or a parametric amplifier or a TWT amplifier. Silicon bipolar transistor is used at lower radar frequencies (below L-band 1215 to 1400 MHz) and the GaAs FET is preferred at higher frequencies. It amplifies the received weak echo signal.
- **Mixer and Local Oscillator**
- These convert RF signal output from RF amplifier to comparatively lower frequency level called Intermediate Frequency (IF). The typical value for pulse radar is 30 MHz or 60 MHz.
- **IF Amplifier**
- IF Amplifier consist of a cascade of tuned amplifier, these can be synchronous, that is all tuned to the same frequency and having identical band pass characteristics. If Aa really large bandwidth is needed, the individual IF may be staggered tuned. The typical value for pulse radar is 30 MHz or 60MHz.
- **Detector**
- Detector is often a schottky-barrier diode which extract the pulse modulation from the IF amplifier output. The detector output is then amplified by the video amplifier to a level where it can be properly displayed on screen directly or via DSP.
- **Display Unit**
- The received video signal are display on the CRT for further observation and actions. Different types of display system which are used in radar.

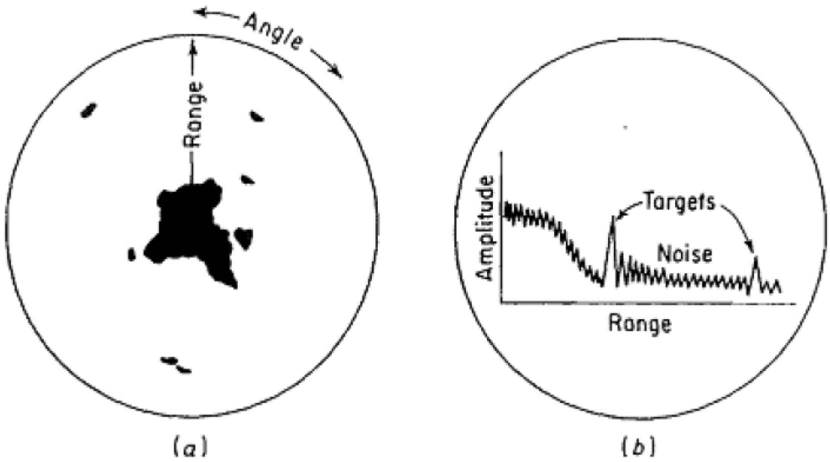
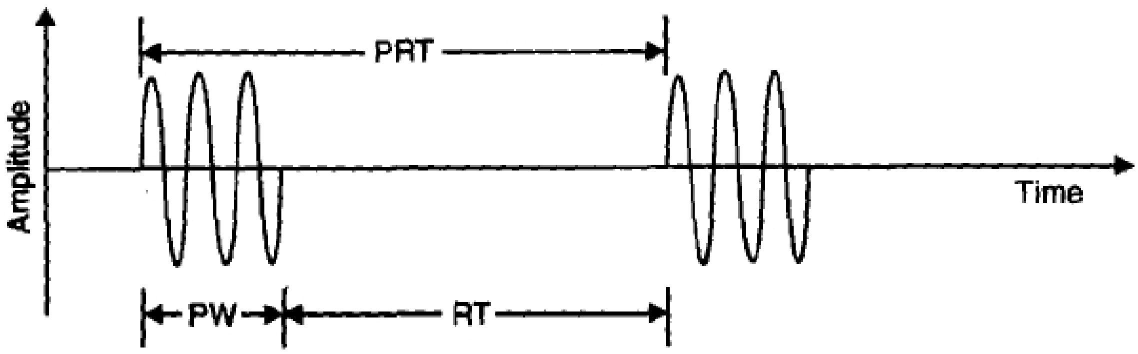


Figure 3.2. (a) PPI presentation displaying range vs. angle (intensity modulation); (b) A-scope Presentation displaying amplitude vs. range (deflection modulation).

- ## Common Parameters of Pulse Radar



- **Pulse Width (PW)**
- PW has units of time and is commonly expressed in ms. PW is the duration of the pulse.
- **Rest Time (RT)**
- RT is the interval between two pulses.
- **Pulse Repetition Time (PRT)**
- PRT is the interval between the start of one pulse and start of another.

$$\mathbf{PRT = PW + RT}$$

- **Pulse Repetition Frequency (PRF)**
- PRF is the number of pulses transmitted per second and is equal to the inverse of PRT

$$\mathbf{PRF = 1/PRT}$$

- **Radio Frequency (RF)**
- RF is the frequency of the carrier wave which is being modulated to form the pulse train. It is expressed in terms of GHz or MHz.
- **Peak Power (P_t)**
- It is defined as the power averaged over that carrier frequency cycle which occur at the maximum of the pulse power.it is usually equal to the one half of the maximum instantaneous power.
- **Average Power (P_{avg})**
- It is defined as the average transmitted power over the pulse repetition time or period.

$$\mathbf{P_{avg} = P_t \times (PW/PRT) = P_t \times PW \times PRF}$$

- **Duty Cycle**
- It is defined as

$$\mathbf{Duty\ Cycle = PW \times PRF}$$

CHAPTER 2 RANGE EQUATION

Prediction of Range Performance

- The simple form of the radar equation expressed the maximum radar range R_{max}, in terms of radar and target parameters:

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

- Where, P_t = Transmitted Power
  G = Antenna Gain
  A_e = Antenna effective aperture
  σ = RADAR cross section
  S_{min} = Minimum Detectable Signal
- All the parameters are to some extent under the control of the radar designer, except for the target cross section σ.
- The radar equation states that if long ranges are desired, the transmitted power must be large, the radiated energy must be concentrated into a narrow beam (high transmitting antenna gain), the received echo energy must be collected with a large antenna aperture (also synonymous with high gain), and the receiver must be sensitive to weak signals.
- In practice, however, the simple radar equation does not predict the range performance of actual radar equipment's to a satisfactory degree of accuracy.
- The predicted values of radar range are usually optimistic. In some cases the actual range might be only half that predicted. Part of this discrepancy is due to the failure of Eq. above to explicitly include the various losses that can occur throughout the system or the loss in performance usually experienced when electronic equipment is operated in the field rather than under laboratory-type conditions.
- Another important factor that must be considered in the radar equation is the statistical or unpredictable nature of several of the parameters. The minimum detectable signal S_{min} and the target cross section σ are both statistical in nature and must be expressed in statistical terms.
- Other statistical factors which do not appear explicitly in Eq. but which have an effect on the radar performance are the meteorological conditions along the propagation path and the performance of the radar operator, if one is employed.
- The statistical nature of these several parameters does not allow the maximum radar range to be described by a single number. Its specification must include a statement of the probability that the radar will detect a certain type of target at a particular range.

Minimum Detectable Signal

- The ability of a radar receiver to detect a weak echo signal is limited by the noise energy that occupies the same portion of the frequency spectrum as does the signal energy.
- The weakest signal the receiver can detect is called the minimum detectable signal.
- The specification of the minimum detectable signal is sometimes difficult because of its statistical nature and because the criterion for deciding whether a target is present or not may not be too well defined.

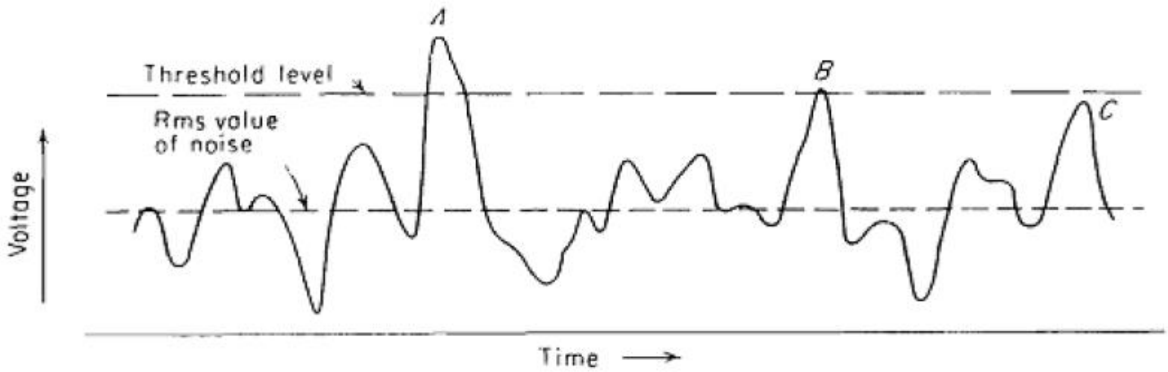


Figure 4.1. Typical envelope of tile radar receiver output as a function of time A, and B and C represent signal plus noise. A & B would be valid detections, but C is a missed detection.

- Detection is based on establishing a threshold level at the output of the receiver. If the receiver output exceeds the threshold, a signal is assumed to be present. This is called **Threshold detection.**
- Consider the output of a typical radar receiver as a function of time (Fig. 4.1). This might represent one sweep of the video output displayed on an A-scope.
- The envelope has a fluctuating appearance caused by the random nature of noise. If a large signal is present such as at A in Fig. 4.1, it is greater than the surrounding noise peaks and can be recognized on the basis of its amplitude.
- Thus, if the threshold level were set sufficiently high, the envelope would not generally exceed the threshold if noise alone were present, but would exceed it if a strong signal were present.
- If the signal were small, however, it would be more difficult to recognize its presence. The threshold level must be low if weak signals are to be detected, but it cannot be so low that noise peaks cross the threshold and give a false indication of the presence of targets.
- The voltage envelope of Fig. 4.1 is assumed to be from a matched-filter receiver. A matched filter is one designed to maximize the output peak signal to average noise (power) ratio.
- It has a frequency-response function which is proportional to the complex conjugate of the signal spectrum. (This is not the same as the concept of "impedance match of circuit theory).
- The ideal matched-filter receiver cannot always be exactly realized in practice, but it is possible to approach it with practical receiver circuits.
- A matched filter for a radar transmitting a rectangular-shaped pulse is usually characterized by a bandwidth B approximately the reciprocal of the pulse width τ, or $B\tau \approx 1$.
- The output of a matched-filter receiver is the cross correlation between the received waveform and a replica of the transmitted waveform. Hence it does not preserve the shape of the input waveform. (There is no reason to wish to preserve the shape of the received waveform so long as the output signal-to-noise ratio is maximized.)

Receiver Noise & Signal to Noise Ratio

- **Receiver Noise:**
- Since noise is the chief factor limiting receiver sensitivity, it is necessary to obtain some means of describing it quantitatively.

- Noise is unwanted electromagnetic energy which interferes with the ability of the receiver to detect the wanted signal. It may originate within the receiver itself, or it may enter via the receiving antenna along with the desired signal.
- If the radar were to operate in a perfectly noise-free environment so that no external sources of noise accompanied the desired signal, and if the receiver itself were so perfect that it did not generate any excess noise, there would still exist an unavoidable component of noise generated by the thermal motion of the conduction electrons in the ohmic portions of the receiver input stages.
- This is called **thermal noise, or Johnson noise**, and is directly proportional to the temperature of the ohmic portions of the circuit and the receiver bandwidth.
- The available thermal-noise power generated by a receiver of bandwidth Bn, (in hertz) at a temperature T (degrees Kelvin) is equal to,

$$\textit{Available Thermal Noise Power} = kTB$$

- Where k = Boltzmann's constant = 1.38 x 10^{-23} J/deg. If the temperature T is taken to be 290 K, which corresponds approximately to room temperature (62°F), the factor kT is 4 x 10^{-21}W/Hz of bandwidth. If the receiver circuitrywere at some other temperature, the thermal-noise power would be correspondingly different.
- A receiver with a reactance input such as a parametric amplifier need not have any significant ohmic loss. The limitation in this case is the thermal noise seen by the antenna and the ohmic losses in the transmission line.
- For radar receivers of the superheterodyne type (the type of receiver used for most radar applications), the receiver bandwidth is approximately that of the intermediate frequency stages.
- It should be cautioned that the bandwidth B, of Eq. is not the 3-dB, or half-power, bandwidth commonly employed by electronic engineers. It is an integrated bandwidth and is given by;

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

- Where H(f) = frequency-response characteristic of IF amplifier (filter) and fo = frequency of maximum response (usually occurs at mid band). When H (f) is normalized to unity at mid band (maximum-response frequency), H (fo) = 1.
- The bandwidth Bn is called the **noise bandwidth** and is the bandwidth of an equivalent rectangular filter whose noise-power output is the same as the filter with characteristic H(f).
- The 3-dB bandwidth is defined as the separation in hertz between the points on the frequency-response characteristic where the response is reduced to 0.707 (3 dB) from its maximum value.
- The 3-dB bandwidth is widely used, since it is easy to measure. The measurement of noise bandwidth however, involves a complete knowledge of the response characteristic H(f).
- The frequency-response characteristics of many practical radar receivers are such that the 3-dB and the noise bandwidths do not differ appreciably.
- Therefore the 3-dB bandwidth may be used in many cases as an approximation to the noise bandwidth.
- The noise power in practical receivers is often greater than can be accounted for by thermal noise alone.
- The additional noise components are due to mechanisms other than the thermal agitation of the conduction electrons.
- The exact origin of the extra noise components is not important except to know that it exists. No matter whether the noise is generated by a thermal mechanism or by some other

mechanism, the total noise at the output of the receiver may be considered to be equal to the thermal-noise power obtained from an" ideal" receiver multiplied by a factor called the noise figure. The noise figure Fn of a receiver is defined by the equation;

$$F_n = \frac{N_0}{kT_0B_nG_a} = \frac{Noise\ out\ of\ practical\ receiver}{Noise\ out\ of\ ideal\ receiver\ at\ std\ temp\ T_0}$$

- ❖ Where No = noise output from receiver, and Ga = available gain. The standard temperature T is taken to be 290 K,
- ❖ The noise No is measured over the linear portion of the receiver input-output characteristic, usually at the output of the IF amplifier before the nonlinear second detector.
- ❖ The receiver bandwidth Bn is that of the IF amplifier in most receivers. The available gain Ga is the ratio of the signal out so to the signal in Si, and kToBn is the input noise Ni in an ideal receiver. Equation above may be rewritten as;

$$F_n = \frac{S_i/N_i}{S_0/N_0}$$

- ❖ The noise figure may be interpreted, therefore, as a measure of the degradation of signal-to noise ratio as the signal passes through the receiver.
- ❖ The noise figure may be interpreted, therefore, as a measure of the degradation of signal-to noise ratio as the signal passes through the receiver.
- ❖ Rearranging Eq. above the input signal may be expressed as;

$$S_i = \frac{kT_0B_nF_nS_0}{N_0}$$

- ❖ If the minimum detectable signal S_{min}, is that value of Si corresponding to the minimum ratio of output (IF) signal-to-noise ratio $(So/No)_{min}$ necessary for detection. then,

$$S_{min} = kT_0B_nF_n\left(\frac{S_0}{N_0}\right)_{min}$$

- ❖ Substituting Eq. discussed above into Eq. earlier results in the following form of the radar equation:

$$R_{max}{}^4 = \frac{P_tGA_e\sigma}{(4\pi)^2kT_0F_nB_n\left(S_0/N_0\right)_{min}}$$

Matched Filter impulse response

- ❖ The frequency response of matched filter is given by;

$$H(f) = G_aS^*(f)\exp(-j2\pi ft_1)$$

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

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

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

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

- ❖ The matched filter may also be specified by its impulse response h(t), which is the inverse Fourier transform of the frequency-response function H(f) is as below;

$$h(t) = \int_{-\infty}^{\infty} H(F)exp(j2\pi ft)df$$

- ❖ Physically, the impulse response is the output of the filter as a function of time when the input is an impulse (delta function).

$$h(t) = G_a \int_{-\infty}^{\infty} S^*(f) \exp\left[-j2\pi f(t_1 - t)\right] df$$

Since $S^*(f) = S(-f)$, we have

$$h(t) = G_a \int_{-\infty}^{\infty} S(f) \exp\left[j2\pi f(t_1 - t)\right] df = G_a s(t_1 - t)$$

- ❖ A rather interesting result is that the impulse response of the matched filter is the image of the received waveform; that is, it is the same as the received signal run backward in time starting from the fixed time t_1.

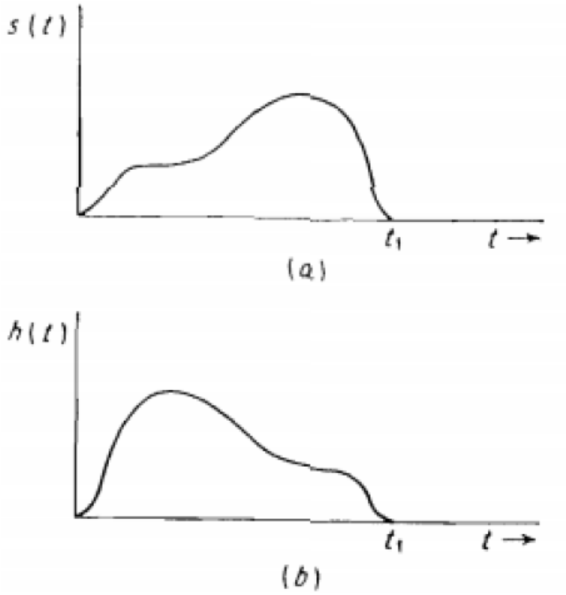


Figure 5.1. (a) Received waveform s(t); (b) impulse response h(t) of the matched filter.

- ❖ Figure 5.1 shows a received waveform s (t) and the impulse response h (t) of its matched filter. The impulse response of the filter, if it is to be realizable, is not defined for $t < 0$. (One cannot have any response before the impulse is applied.)
- ❖ Therefore we must always have $t < t_1$. This is equivalent to the condition placed on the transfer function H(f) that there be a phase shift exp ($-j2\Pi f t_1$).
- ❖ However, for the sake of convenience, the impulse response of the matched filter is sometimes written simply as s (-t).

Integration of radar Pulses

- ❖ Many pulses are usually returned from any particular target on each radar scan and can be used to improve detection. The number of pulses n_B returned from a point target as the radar antenna scans through its beam width is;

$$n_B = \frac{\theta_B f_p}{\theta_s} = \frac{\theta_B f_p}{6\omega_m}$$

where θ_B = antenna beamwidth, deg
f_p = pulse repetition frequency, Hz
θ_s = antenna scanning rate, deg/s
ω_m = antenna scan rate, rpm

- Typical parameters for a ground-based search radar might be pulse repetition frequency, 1.5° beam width, and antenna scan rate 5 rpm (30°/s). These parameters result in 15 hits from a point target on each scan.
- The process of summing all the radar echo pulses for the purpose of improving detection is **called integration**.
- Many techniques might be employed for accomplishing integration. All practical integration techniques employ some sort of storage device. Perhaps the most common radar integration method is the cathode-ray-tube display combined with the integrating properties of the eye and brain of the radar operator.
- Integration may be accomplished in the radar receiver either before the second detector (in the IF) or after the second detector (in the video). A definite distinction must be made between these two cases.
- Integration before the detector is **called pre-detection**, or coherent, integration, while integration after the detector is **called post-detection**, or non-coherent, integration. Predetection integration requires that the phase of the echo signal be preserved if full benefit is to be obtained from the summing process.
- On the other hand, phase information is destroyed by the second detector; hence post detection integration is no concerned with preserving RF phase. For this convenience, post-detection integration is not as efficient as pre-detection integration.
- If n pulses, all of the same signal-to-noise ratio, were integrated by an ideal Predetection integrator, the resultant, or integrated, signal-to-noise (power) ratio would be exactly n times that of a single pulse.
- If the same n pulses were integrated by an ideal post-detection device, the resultant signal-to-noise ratio would be less than n times that of a single pulse.
- This loss in integration efficiency is caused by the nonlinear action of the second detector, which converts some of the signal energy to noise energy in the rectification process.
- The comparison of pre-detection and post-detection integration may be briefly summarized by stating that although post-detection integration is not as efficient as predetection integration, it is easier to implement in most applications.
- Post detection integration is therefore preferred, even though the integrated signal to noise ratio may not be as great. An alert, trained operator viewing a properly designed cathode-ray tube display is a close approximation to the theoretical post-detection integrator.
- The efficiency of post-detection integration relative to ideal pre-detection integration has been computed by Marcum when all pulses are of equal amplitude. The integration efficiency may be defined as follows:

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

- $(S/N)_1$ = value of signal-to-noise ratio of a single pulse required to produce given probability of detection (for n = 1).
- $(S/N)_n$ = value of signal-to-noise ratio per pulse required to produce same probability of detection when n pulses are integrated.
- The improvement in the signal-to-noise ratio when n pulses are integrated post detection is nEi(n) and is the **integration-improvement factor.**
- The radar equation with n pulses integrated can be written as;

$$\boldsymbol{R_{max}}^4 = \frac{\boldsymbol{P_t G A_e \sigma}}{(4\boldsymbol{\pi})^2 \boldsymbol{k T_0 F_n B_n} \left({S_0}/{N_0} \right)_n}$$

$$R_{max}{}^{4} = \frac{P_t G A_e \sigma\, n\, E_i(n)}{(4\pi)^2 k T_0 F_n B_n \left({}^{S_0}/_{N_0}\right)_1}$$

Radar Cross Section of Target

- Radar cross section is a property of a scattering object or target that is included in the radar eq. to represent the echo signal returned to the radar by target.

$$Power\ Density\ of\ echo\ signal = \frac{P_t G}{4\pi R^2}\frac{\sigma}{4\pi R^2}$$

- In other terms,

$$\sigma = \frac{Power\ reflected\ toward\ source\ per\ unit\ solid\ angle}{Incident\ power\ density\ per\ 4\pi}$$

- Where,

  R = distance between RADAR and target
  E_r = Reflected field strength at RADAR
  E_i = Strength of incident field at target

- The radar cross section of a target is the (fictional) area intercepting that amount of power which, when scattered equally in all directions.
- Scattering and diffraction are variations of the same physical process.
- When an object scatters an electromagnetic wave, the scattered field is defined as the difference between the total field in the presence of the object and the field that would exist if the object were absent (but with the sources unchanged). On the other hand, the diffracted field is the total field in the presence of the object.
- With radar backscatter, the two fields are the same, and one may talk about scattering and diffraction interchangeably.
- The scattered field, and hence the radar cross section, can be determined by solving Maxwell's equations with the proper boundary conditions applied.
- Unfortunately, the determination of the radar cross section with Maxwell's equations can be accomplished only for the most simple of shapes, and solutions valid over a large range of frequencies are not easy to obtain. The radar cross section of a simple sphere is shown in Fig. 6.1

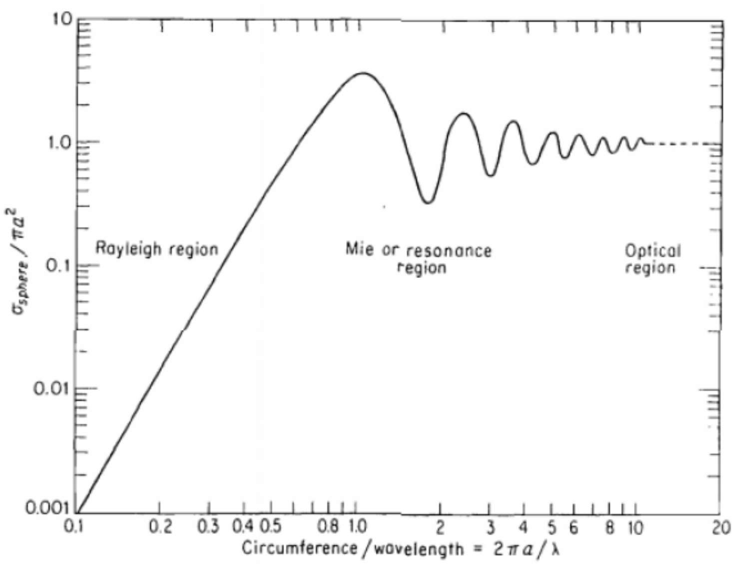
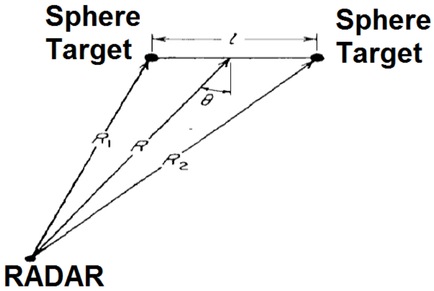


Figure 6.1. Radar cross section of the sphere. a = radius; λ = wavelength

- The region where the size of the sphere is small compared with the wavelength $2\pi a/\lambda << 1$ is called the Rayleigh region, after Lord Rayleigh who, in the early 1870 first studied scattering by small particles.
- Lord Rayleigh was interested in the scattering of light by microscopic particles, rather than in radar.
- The cross section of objects within the Rayleigh region varies as λ^{-4}.
- Rain and Clouds are essentially invisible to radars which operate at relatively long wavelengths (low frequencies).
- The usual radar targets are much larger than raindrops or cloud particles, and lowering the radar frequency to the point where rain or cloud echoes are negligibly small will not seriously reduce the cross section of the larger desired targets.
- On the other hand, if it were desired to actually observe, rather than eliminate, raindrop echoes, as in a meteorological or weather-observing radar, the higher radar frequencies would be preferred.
- At the other extreme from the Rayleigh region is the optical region, where the dimensions of the sphere are large compared with the wavelength $2\pi a/\lambda >> 1$.
- For large $2\pi a/\lambda$ the radar cross section approaches the optical cross section πa^2.
- In between the optical and the Rayleigh region is the Mie or resonance, region.
- The maximum value is 5.6 dB greater than the optical value, while the value of the first null is 5.5 dB below the optical value.

COMPLEX TARGET:-

- The radar cross section of complex targets such as ships, aircraft, cities, and terrain are complicated functions of the viewing aspect and the radar frequency.
- A complex target may be considered as comprising a large number of independent objects that scatter energy in all directions.
- The relative phases and amplitudes of the echo signals from the individual scattering objects as measured at the radar receiver determine the total cross section.
- The phases and amplitudes of the individual signals might add to give a large total cross section, or the relationships with one another might result in total cancellation.
- In general, the behaviour is somewhere between total reinforcement and total cancellation.
- If the separation between the individual scattering objects is large compared with the wavelength-and this is usually true for most radar applications-the phases of the individual signals at the radar receiver will vary as the viewing aspect is changed and cause a scintillating echo.
- Consider the scattering from a relatively "simple" complex target consisting of two equal, isotropic objects (such as spheres) separated by a distance l.



- The separation I <= $c\tau/2$.
  Where, c = velocity of propagation and
  τ = pulse duration.

- ❖ Another restriction placed on l is that it be small compared with the distance R from radar to target.
- ❖ Furthermore, $R_1 = R_2 = R$
- ❖ The cross sections of the two targets are assumed equal and are designated σ_0.
- ❖ The composite cross section σ_r, of the two scatterers is The ratio σ_r / σ_0 ;

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

- ❖ σ_r / σ_0 can be anything from a minimum of zero to a maximum of four times the cross section of an individual scatterer.

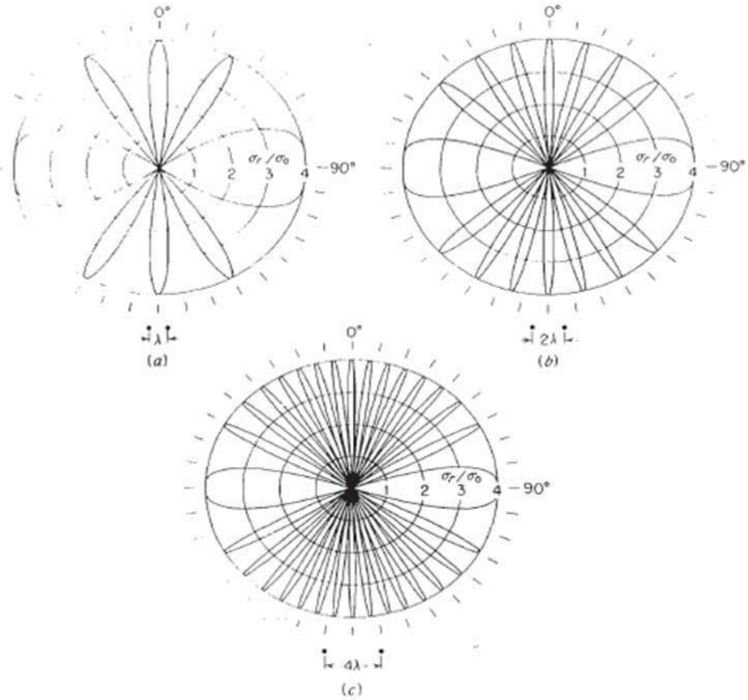


Figure 6.2. Polar plot of σ_r / σ_0 for complex target (a) l= λ (b) l=2λ (c) l= 4λ

Cross section Fluctuations

- ❖ The discussion of the minimum signal-to-noise ratio assumed that the echo signal received from a particular target did not vary with time.
- ❖ However, the echo signal from a target in motion is almost never constant.
- ❖ Variations in the echo signal may be caused by meteorological conditions, the lobe structure of the antenna pattern, equipment instabilities, or variations in the target cross section.
- ❖ For larger target (complex target) echo scattering center has an amplitude & phase that is independent of the amplitude & phase is different from other scattering centers.
- ❖ One straightforward method for a fluctuating radar cross section is to select small value of cross section which has high probability of being exceeded of all the time.
- ❖ Another method is based on probability density function (PDF).
- ❖ It gives value between σ and dσ.
- ❖ In addition to PDF the variation of cross section fluctuation is done with time.
- ❖ The variation of cross section fluctuation is differ from receiver noise means receiver noise is independent from the pulse to pulse.

SWERLING TARGET MODELS

- **Case 1:-**
- The echo pulses received from a target on any one scan are of constant amplitude throughout the entire scan but are independent (uncorrelated) from scan to scan.
- An echo fluctuation of this type will be referred to as scan-to-scan fluctuation.
- The probability - density function for the cross section σ is;

$$p(\sigma) = \frac{1}{\sigma_{av}} exp\left(-\frac{\sigma}{\sigma_{av}}\right) \qquad \sigma \geq 0$$

- **Case 2:-**
- The PDF for the target cross section is also given by

$$p(\sigma) = \frac{1}{\sigma_{av}} exp\left(-\frac{\sigma}{\sigma_{av}}\right) \qquad \sigma \geq 0$$

- But the fluctuation is more rapid than in case 1 and are taken to be independent from pulse to pulse instead of from scan to scan.
- **Case 3:-**
- In this case the fluctuation is assumed to be independent from the scan to scan as in case 1 but the PDF is given by;

$$p(\sigma) = \frac{4\sigma}{{\sigma_{av}}^2} exp\left(-\frac{2\sigma}{\sigma_{av}}\right) \qquad \sigma \geq 0$$

- **Case 4:-**
- The fluctuation for pulse to pulse is same as case 3.
- Pulse to pulse change in frequency is called **freq. agility**.
- The probability-density function assumed in cases 1 and 2 applies to a complex target consisting of many independent scatterers of approximately equal echoing areas.
- Cases 3 and 4 is more indicative of targets that can be represented as one large reflector together with other small reflectors.
- For purposes of comparison, the non-fluctuating cross section will be called ***case 5***.

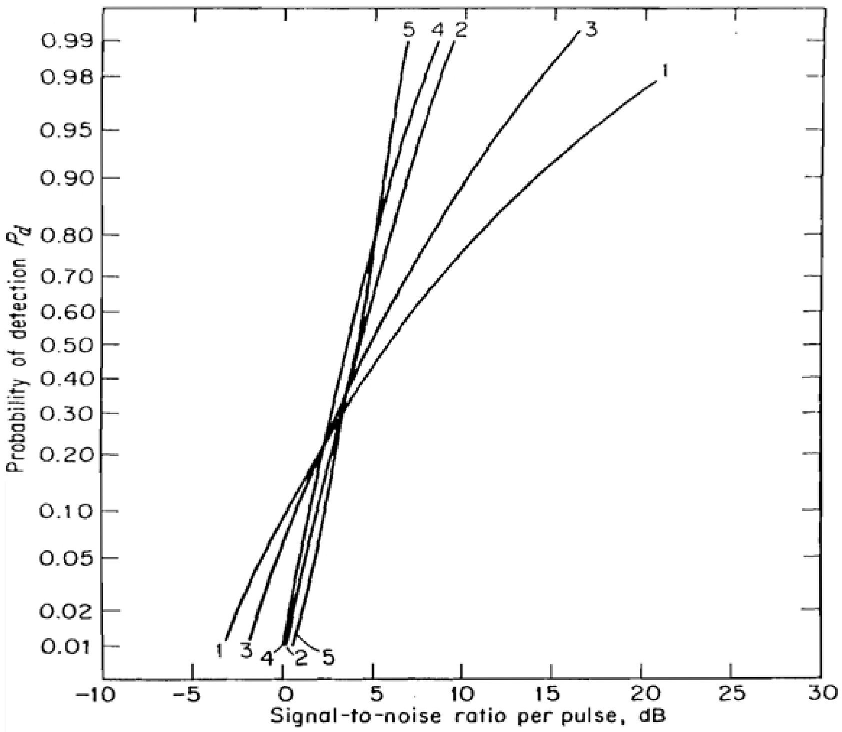


Figure 7.1. P_d v/s S/N plot

Transmitter Power

- The power Pt in radar range eq. is called peak power

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

- The peak pulse power as used in the radar equation is not the instantaneous peak power of a sine wave.
- It is defined as the power averaged over that carrier-frequency cycle which occurs at the maximum of the pulse of power.
- If the transmitted waveform is a train of rectangular pulses of width τ and pulse repetition period Tp = 1/ f p , the average Power is related to the peak power by,

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

- The ratio P_{av}/P_t, τ/T_p or τf_p is called the duty cycle of the RADAR.

$$R_{max}{}^4 = \frac{P_t G A_e \sigma \, n \, E_i(n)}{(4\pi)^2 k T_0 F_n B_n \tau \left({S_0}/{N_0}\right)_1 f_p}$$

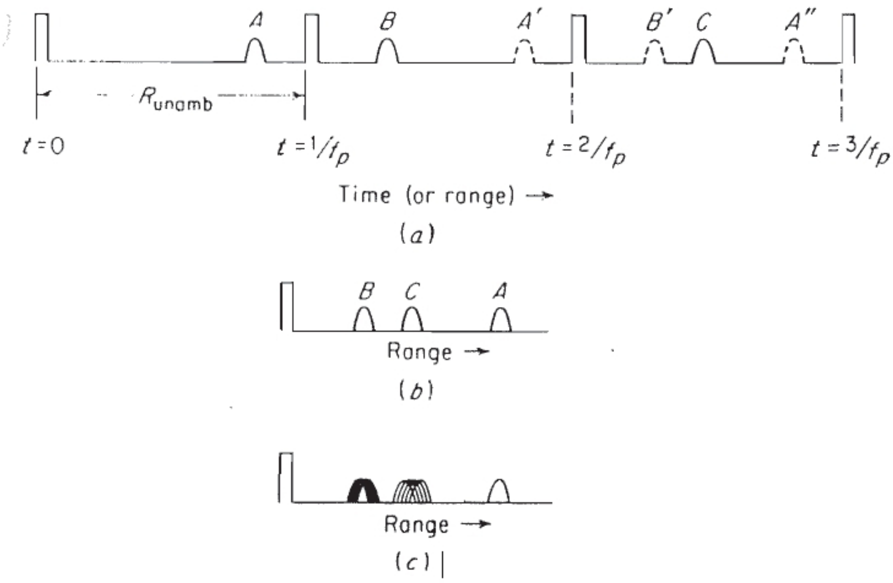
- Here, $E_t = P_{av}/f_p$

$$R_{max}{}^4 = \frac{E_t G A_e \sigma \, n \, E_i(n)}{(4\pi)^2 k T_0 F_n B_n \tau \left({S_0}/{N_0}\right)_1}$$

- Where, E_i = Total energy of the n pulses which is equals to nE_p

Pulse Repetition Frequency and Range Ambiguities

- The pulse repetition freq.(prf) is determined primarily by the maximum range at which targets are expected.
- If the prf is made too high , the likelihood of obtaining target echoes from the wrong pulse transmission is increased.
- Echo signal received after an interval exceeding the pulse-repetition period are called ***multiple time around echoes.***
- Now consider the three targets labeled ***A, B, and C in Fig.***



- ❖ Target A is located within the maximum unambiguous range Runamb of the radar,
- ❖ target B is at a distance greater than Runamb but less than 2RUnamb
- ❖ while target C is greater the 2Runabm but less than 3RUnamb The appearance of the three targets on an A-scope is sketched in Fig. c
- ❖ The multiple-time-around echoes on the A-scope cannot be distinguished from proper target echoes actually within the maximum unambiguous range.
- ❖ Only the range measured for target A is correct; those for B and C are not.
- ❖ One method of distinguishing multiple-time-around echoes from unambiguous echoes is to operate with a varying pulse repetition frequency.
- ❖ Rtrue = f1 or (f1+Run1) or (f1+Run2) or …
- ❖ The correct range is that value which is the same with the two PRF, generally three PRF are often use to resolve range ambiguities.

System Losses

- ❖ The important factors omitted from the simple radar equation was the losses that occurs throughout the radar system.
- ❖ System losses define by Ls.
- ❖ Loss (number greater than unity) and efficiency (number less than unity) are used interchangeably. One is simply the reciprocal of the other.
- ❖ **Losses occurs due to,**
  1. Loss due to integration.
  2. Loss due to fluctuating cross section.
  3. Loss due to change in radar cross section of target.
  4. Losses due to transmission line.
  5. Losses due to various mechanical part of radar system

- ❖ **Types of losses:-**
- ❖ Cfswc
  1. Microwave plumbing loss.
  2. Duplexer loss.
  3. Antenna loss.
  4. Scanning loss.
  5. Radome.
  6. Signal processing loss.
  7. Loss in Doppler processing radar.
  8. Collapsing loss.
  9. Operator loss.
  10. Equipment degradation.
  11. Transmission loss.
  12. Radar system losses- the seller and the buyer.
  13. Propagation effect

- ❖ **Microwave plumbing loss:-**
- ❖ There is always loss in transmission line that connect Tx and Rx.
- ❖ In addition there can be loss in the various microwave components such as duplexer, receiver protector, directional coupler, transmission line connector, bend in transmission line, etc.

- **Duplexer loss:-**
- The loss due to duplexer that is protect Tx and Rx.
- Eg. Gas duplexer, solid state duplexer.

- **Antenna loss:-**
- Beam shape loss.
- The antenna gain that appears in the radar equation was assumed to be a constant equal to the maximum value.
- But in reality the train of pulses returned from a target with a scanning radar is modulated in amplitude by the shape of the antenna beam.

- **Scanning loss:**
- When the antenna scan rapidly enough, relative to the round trip time of the echo signal, the antenna gain in the direction of target on transmit might not be the same as that on receive.
- This result in an additional loss called scanning loss.

- **Phased array losses:-**
- Some phased array radar have additional transmission losses due to the distribution n/w that connects RX and Tx to each of the many element of array.

- **Signal processing loss:-**
- Sophisticated signal processing is prevalent in modern radars and is very important for detecting target in clutter and in extracting information from radar echo signals.

The factor described below can also introduced significant loss:

1. Matched & Non-matched filter
2. Constant false alarm
3. Automatic integrator
4. Threshold level
5. Limiting loss
   Eg. Pulse compression processing to remove amplitude fluctuation.
6. Sampling loss

- **Losses in Doppler processing radar:-**
- This kind of loss occur due to Doppler frequency.

- **Collapsing loss:-**
- If the radar were to integrate additional noise sample along with signal-pulse-noise pulses, the added noise would result in a degradation called **collapsing loss.**

- **Operator loss:-**
- An alert, motivated, and well-trained operator should perform as well as described by theory.
- However, when distracted, tired, overloaded, or not properly trained, operator performance will decrease.
- There is little guidance available on how to account for the performance of an operator.
- Based on both empirical and experimental results, one gives the operator efficiency factor as $$\boldsymbol{\rho_0 = 0.7(P_d)^2}$$

- **Equipment degradation:-**
- It is common for radar operated under field conditions to have performance than when they left the factory.
- This loss of performance can be recognized by regular testing the radar, especially with built in test equipment that automatically indicating when equipment deviates from specifications.

- **Transmission loss:-**
- The theoretical one way loss in dB per 100 feet for standard transmission line.
- Since the same transmission line generally is used for transmission and reception, so the loss to be inserted in the radar eq. is twice the one-way loss.
- Flexible waveguide and coaxial line can have higher loss compare to conventional waveguide.
- At lower freq. transmission line introduce less loss.
- At higher freq. transmission line introduce more loss.
- Connection loss is also present in transmission line.

- **Radar system losses- the seller & the buyer:-**
- There is no universally agreed upon procedure for determining system losses or what losses should be considered when predicting radar performance.

Propagation Effects

- Electromagnetic wave travel through empty space in straight line at the speed of light, but REFRECTIVE INDEX of the atmosphere affects both the travel path and speed of the EM wave.
- The path of EM wave in atmosphere is direct or reflected, usually is slightly curved.
- Speed of EM wave also affected by temp., pressure etc.
- As altitude increases, the combined effect of these influences decreases so speed of EM wave increases but it travel slightly downward.
- The effect on non-free space propagation on the radar are of five category as below.
    1. Refraction
    2. Index of refraction
    3. Temp. Inversion
    4. Moisture lapse

- **Ducting (super refraction):-**
- Either temperature inversion or moisture lapse, alone or in combination can cause a larger change in the refraction index of lowest few-hundred feet of the atmosphere.
- The result is a greater bending of the radar waves passing through the abnormal condition.
- The increased bending in such a situation is referred as **DUCTING**.
- Water particles and dust particles diffuse the radar energy through absorption, scattering, reflection so less energy strikes to the target.
- So range of radar is varies widely with atmosphere.

Other Consideration

- Prediction of radar range**.** In this chapter, some of the more important factors that enter into the radar equation for the prediction of range were briefly considered. The radar equation**,** with the modifications indicated in this chapter, becomes

$$\boldsymbol{R_{max}}^{4} = \frac{\boldsymbol{P_{av} G A_e \, \rho_a \, \sigma \, n \, E_i(n)}}{\boldsymbol{(4\pi)^2 k T_0 F_n B_n \tau \, f_p \left({S_0}/{N_0}\right)_1 L_s}}$$

- Where,

  R_{max} = Maximum Radar range, m
  G = Antenna Gain
  A_e = Antenna Aperture, m^2
  ρ_e = Antenna Efficiency
  n = number of hits integrated
  $E_i(n)$ = Integration Efficiency
  L_s = System Losses
  σ = Radar Cross section
  F_n = Noise Figure
  k = Boltzmann's constant
  T_0 = Standard temperature = 290K
  B = Receiver bandwidth
  τ = pulse width
  f_p = Pulse repetition frequency, Hz
  $(S/N)_1$ = signal to noise ratio required at receiver output (based on single hit detection)

Antenna Parameters

- Almost all radars use directive antennas for transmission and reception. On transmission, the directive antenna channels the radiated energy into a beam to enhance the energy concentrated in the direction of the target.

- **Antenna Gain:-**
- The antenna gain G is a measure of the power radiated in a particular direction by a directive antenna to the power which would have been radiates in the same direction by an omnidirectional antenna with 100 percent efficiency.
- More precisely, the power gain of an antenna used for transmission is;

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

- Note that the antenna gain is a function of direction. If it is greater than unity in some directions, it must be less than unity in other directions. This follows from the conservation of energy.
- One of the basic principles of antenna theory is that of ***reciprocity,*** which states that the properties of an antenna are the same no matter whether it is used for transmission or reception.

- **Beam Shape**

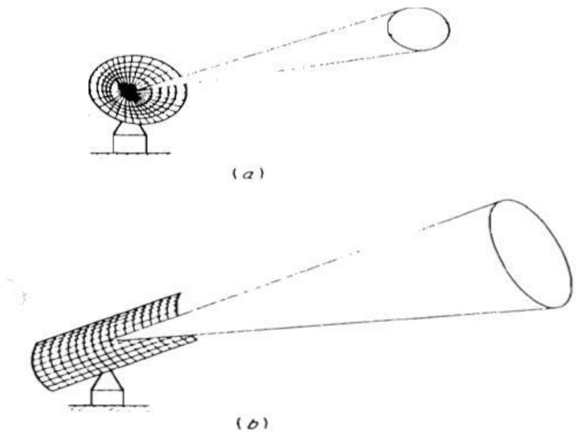


Figure 10.1. (a) Pencil beam antenna pattern (b) Fan beam antenna pattern

- The antenna pattern is a plot of antenna gain as a function of the direction of radiation. (A typical antenna pattern plotted as a function of one angular coordinate is shown in Fig. 10.1
- Antenna beam shapes most commonly employed in radar are the pencil beam (Fig. 10.1(a)) and the fan beam (Fig. 10.1(b)).
- The pencil beam is axially symmetric, or nearly so. Beam widths of typical pencil-beam antennas may be of the order of a few degrees or less.
- Pencil beams arc commonly used where it is necessary to measure continuously the angular position of a target in both azimuth and elevation, as, for example, the target tracking radar for the control of weapons or missile guidance.
- The pencil beam may be generated with a metallic reflector surface shaped in the form of a paraboloid of revolution with the electromagnetic energy fed from a point source placed at the focus.
- Usually, operational requirements place a restriction on the maximum scan time (time for the beam to return to the same point in space) so that the radar cannot dwell too long at any one radar resolution cell.
- This is especially true if there is a large number of resolution cells to be searched.
- The number of resolution cells can be materially reduced if the narrow angular resolution cell of a pencil-beam radar is replaced by a beam in which one dimension is broad while the other dimension is narrow, that is, a fan-shaped pattern.
- One method of generating a fan beam is with a parabolic reflector shaped to yield the proper ratio between the azimuth and elevation beam widths. Many long-range ground based search radars use a fan-beam pattern narrow in azimuth and broad in elevation.

- **Cosecant-Squared Antenna Pattern:-**
- The coverage of a simple fan beam is usually inadequate for targets at high altitudes close to the radar. The simple fan-beam antenna radiates very little of its energy in this direction.

$$G(\phi) = G(\phi_0)\frac{\csc^2 \phi}{\csc^2 \phi_0} \qquad \text{for } \phi_0 < \phi < \phi_m$$

- Where $G(\varphi)$ = gain at elevation angle φ, and φ_0 and φ_m, are the angular limits between which the beam follows a $\csc^2$ shape.
- From $\varphi = 0$ to $\varphi = \varphi 0$, the antenna pattern is similar to a normal antenna pattern. But from $\varphi = 0$ to $\varphi = \varphi_m$ the antenna gain varies as $\csc^2 \varphi$.
- Ideally, the upper limit φ_m, should be 90^o.But it is always less than this with a single antenna because of practical difficulties.

- The cosecant-squared antenna has the important property that the echo power P, received from a target of constant cross section at constant altitude *h* is independent of the target's range R from the radar. Substituting the gain of the cosecant-squared antenna [above eq.] into the simple radar equation gives;

$$P_r = \frac{P_t G^2(\varphi_0) csc^4 \lambda^2 \sigma}{(4\pi)^3 csc^4 \phi_0 R^4} = K_1 \frac{csc^4 \phi}{R^4}$$

- Where K_1 is a constant. The height h of the target is assumed constant, and since csc ϕ = R/h, the received power becomes.

$$P_r = {K_1}/{h^4} = K_2$$

- Where, K_2 is constant.

- **Effective Area and Beam width:-**
- The maximum gain of an antenna is related to its physical area A (aperture) by;

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

- Where, ρ = antenna efficiency and λ = wavelength of radiated energy.
- A typical reflector antenna with a parabolic shape will produce a beam width approximately equal to;

$$\theta^0 = \frac{65\lambda}{l}$$

- Where l = dimension of the antenna.

Surface / Ground Clutter

- Generally, we say the clutters which are appearing on the radar scope due to the reflection from the ground, known as ground clutter.
- The amount of clutter will depend upon the height of the antenna above the ground. Clutter will be more if we increase the height of the antenna above ground.
- For ground based radar clutter signals are mainly from the permanent or fixed targets.
- Whereas for air born radar the clutter is varying continuously because of the movement of the aircraft.
- The echo signal received from the buildings, towers and other man-made structure give stronger echo than other countryside because of the presence of flat reflecting surface and corner reflection.
- River, road and runway backscatter little energy but are visible on radar PPI scope.
- A PPI representation of typical ground echoes might consist of many bright spots if the beam width of the antenna is broad so that individual target is not resolved.
- Due to the ever-changing nature of most clutter echoes with time, the conglomeration of the spot on the PPI scope displaying clutter may differ from scan to scan.
- The ground based radars will receive the strong signals from the hills, mountains or other surfaces which are oriented properly.
- The reflection from hills, and land surfaces are usually very intense that the reflection from the desired target such as aircraft limits the detection capability of the radar.
- An MTI receiver may be used to minimize the ground clutter and make possible to display the echoes of desired moving target.
- The intensity of ground clutter echoes may be further enhanced by super refractions effect.

Clutter Cross Section

- While describing the clutter from the ground or sea, the cross-section per unit of Intercepted area (σ^0) is often taken as a measure of echo strength instead of the more usual cross-section (σ) defined.
- With an extended target such as clutter, σ is a function of the beam which is illuminating the ground or the sea, whereas, σ^0 is almost independent of the size of the clutter patch is illuminated.
- In some cases the parameter $\gamma = \frac{\sigma^0}{\sin\phi}$ has been used to measure the echo-signal return, where ϕ is the angle of depression of the antenna beam as measured from the horizontal.
- If the C is the velocity of propagation and T is the pulse width, all the individual scatters located within the distance CT/2 along the line of propagation results to the composite clutter echo. It can be observed in the figure shown as below, that σ^0 is equal to $\frac{\sigma}{\left[\left(\frac{cT}{2}\right)R\theta_B \sec\phi\right]}$ where σ is the total cross section of all the individual scatterers positioned within track of the antenna beam illuminating on the earth surface, R is the range and Θ_B is half power beam width.

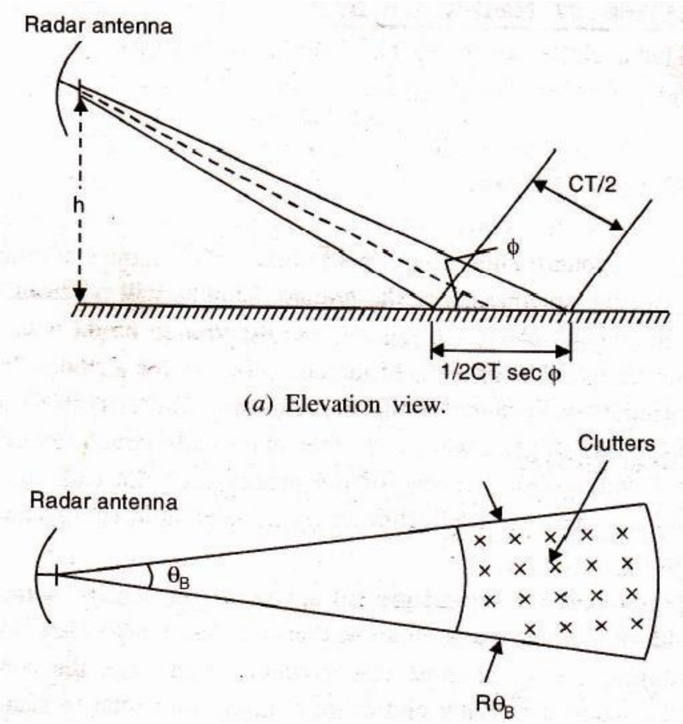


Figure 11.1 Geometrical representation of radar clutter

- It is difficult to describe the specification of the radar cross-section of ground return because of the many different types of terrain and many more factors which influencing the properties of scattering. The main parameters which are affecting radar scattering from the ground are as follows:
  - (i) Roughness of the surface
  - (iii) Polarization
  - (ii) Incident angle
  - (iv) Frequency
  - (v) Dielectric constant of the reflecting surface.
- It is important to have the knowledge for search radar and air borne interceptions radar in order to predict the amount of the echo with the desired target signal must compete.

- ## Sea Clutter
- The reflection of radar energy from the surface of the sea is known as sea echo or sea clutters. Sea clutter will cause serious problem for the radar are positioned or operating near the sea surface. The magnitude of the sea clutter return signal scattered in the direction of the radar depends upon incident angle with the horizontal, polarization and the wavelength of the radar energy, the wind and the state of the sea.
- We may consider that the surface of the sea having of a number of individual scatters which reflect the EM energy from the radar. The average echo signal reflected from all the independent scatters ,ruminated by the antenna beam is given by;

$$P_r = \frac{P_t G^2 . \lambda^2}{(4\pi)^2 R^4} \sum_i \bar{\sigma}_i$$

- Where,

  P_r = Average echo signal
  P_t = Transmitted power
  G = Gain of the antenna
  λ = Wavelength
  R = Range
  $\bar{\sigma}_i$= Time avg. radar cross section of the i^{th} scatterer.
- Above eq. is simply derived the simple form of radar range eq. if σ_0 is defined as the avg. cross – section per unit area

$$\sum_i \bar{\sigma}_i = \frac{\sigma^0 R \theta_B c T}{2}$$

- Then simple radar eq. becomes;

$$\overline{P_r} = \frac{P_t G^2 \lambda^2 \theta_B}{(4\pi)^3 R^3} \frac{cT}{2} \sigma^0$$

- In the above case the received echo power as the extended clutter may varies inversely third power of the range instead of the fourth power relationship obtained for a single point target. This is the result of the extended nature of the clutter.
- As the range increasing the more the beam will spread and there will be more number of scatterer illuminated.
- There is another case of a pencil beam antenna at large depression angles. The pulse packet will cover a much region, of the sea surface from the area intercepted by the beam. The summation may be determined by the antenna beam width in azimuth and in elevations rather than the width of the pulse.

$$\sum_i \bar{\sigma}_i = \frac{\sigma^0 R^2 \theta_B \phi_B}{\sin \phi}$$

$$\overline{P_r} = \frac{P_t G^2 \lambda^2 \theta_B \phi_B \sigma^0}{(4\pi)^3 R^2 \sin \phi}$$

- ## Weather Clutter
- Radars at the lower frequencies are not bothered by meteorological or weather effects, but at the higher frequencies, weather echoes may be quite strong and mask the desired target signals just as any other unwanted clutter signal.
- Whether the radar detection of meteorological particles such as rain, snow, or hail is a blessing or a curse depends upon one's point of view. Weather echoes are a nuisance to the

radar operator whose job is to detect aircraft or ship targets. Echoes from a storm, for example, might mask or confuse the echoes from targets located at the same range and azimuth.

- On the other hand, radar return from rain, snow, or hail is of considerable importance in meteorological research and weather prediction. Radar may be itself to give an upto date pattern of precipitation in the area around the radar.
- It is a simple and inexpensive gauge for measuring the precipitation over relatively large expanses. As a rain gauge it is quite useful to the hydrologist in determining the amount of water falling into a watershed during a given period of time.
- Radar has been used extensively for the study of thunderstorms, squall lines, tornadoes, hurricanes, and in cloud-physics research. Not only is radar useful as a means of studying the basic properties of these phenomena, but it may also be used for gathering the information needed for predicting the course of the weather.
- Another important application of radar designed for the detection of weather echoes is in airborne weather-avoidance radars, whose function is to indicate to the aircraft pilot the dangerous storm areas to be avoided
- Within radar resolution cell there are many individual rain drops with cross section σ_i so;
- Within the radar resolution cell there are many rain drops , each have cross selection σ_i, so;

Total cross section area $\sigma_c = V_c\,\eta = V_c \Sigma\, \sigma_i$

- Where,

  η = radar cross section per unit area
  V_c = volume of the radar resolution cell

The summation is taken over the unit volume $V_c = (\pi/4)\,(R\Theta_B)\,(R\Theta_\varphi)(c\tau/2)\,(l/2 \ln 2)$

- Where,

  R = Range
  Θ_B = Horizontal half power beam width
  Θ_φ = vertical half power beam width
  τ = Pulse duration
  c = speed of propagation

CHAPTER 3 ANTENNAS FOR RADAR & NAVIGATION

Introduction

- An antenna has either to receive energy from an" electromagnetic field or to radiate electromagnetic waves produced by a high frequency generator. Types of antenna mainly depend upon the application of the radar' For example long-range detection radar (surveillance radar) needs large aperture of the antenna.
- The Antenna used normally for radar applications different from the antenna used in communication system' Radar antenna with the shaped directive pattern can be scanned either mechanically or electronically.
- In general an antenna is a transmission device, or transducer, between a guided wave (transmission line) and a free space wave or vice versa. The basic parameter of an antenna will be discussed in the brief in the following section.
- The radar antenna acts as a transducer, which converts electrical pulses from the transmitter to the free space in the form of EM waves and receives the reflected EM signalsfromthetargetinfreespaceandconvertsitintoelectricalsignals.
- In the radar equation we have studied about, the antenna gain and the aperture area of the antenna. For the large antenna gain the effective aperture area of the antenna must be large. Both the parameter is proportional to each other.
- If we say in simple terms, the function of the radar antenna in transmitting mode should concentrate the radiated energy into a shaped beam to the desired direction. And in the receiving mode, from the target and deliver it to the receiver.
- Mostly radars, as we know, are operated in the microwave frequencies region, So the main advantage of microwave frequencies for radar application in that an aperture of relatively small physical size but it is quite large enough in terms of wavelength can be obtained. The antenna having high gain with the narrow beam widths are possible at microwave frequency. But it is quite difficult to achieve at HF.

Fundamental Antenna Concept / Parameters

- Important parameters of radar antennas, discussed here in brief. Which are as follows:
    1. Directivity or Directive gain.
    2. Power gain.
    3. Effective receiving aperture or total scattering cross section.
    4. Polarizations.
    5. Side lobes.

P_t =Power generated by the transmitter
L_t, L_r= Transmitting-path and receiving-path loss
L_{ta}, L_{ra}= Transmitting antenna loss and receiving antenna loss
R= Distance of separation between the antennas
S= Signal power available at the lossless antenna output
S_r= Signal power available at the receiver input

- Above data is given for figure 13.1

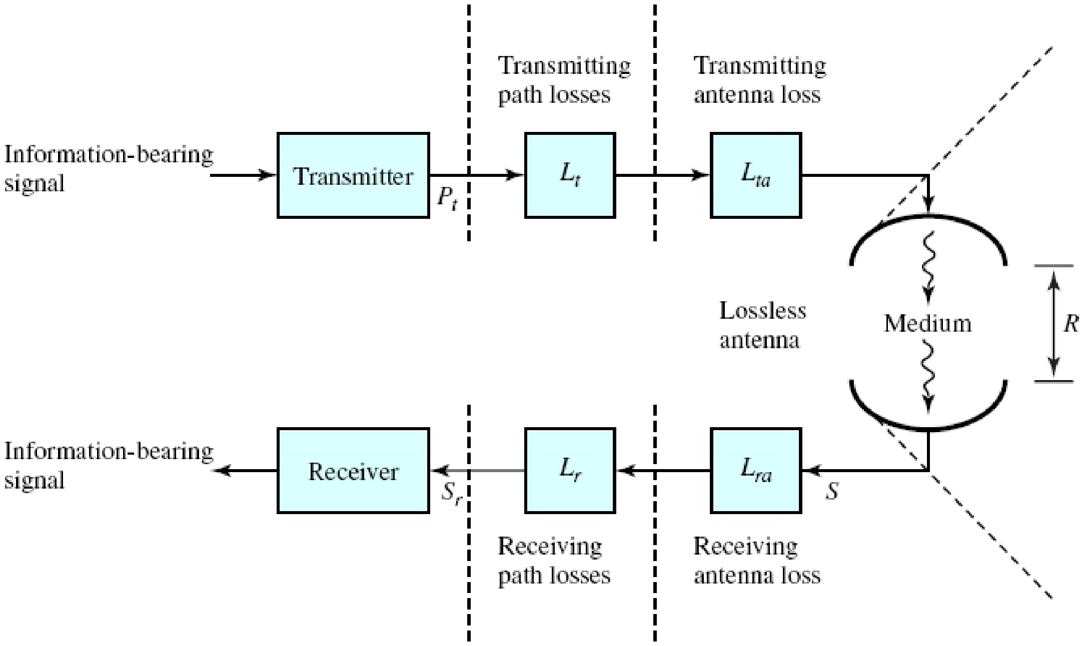


Figure 13.1 Communication system involving antennas

- **Functions of an Antenna:**
- Antenna is a metallic object, often a wire or collection of wire which is used to perform following functions :
  - It couples the transmitter output to the free space, or the received input to the receiver.
  - It must be capable of radiating or receiving the electromagnetic waves.
  - It converts the high frequency current into electromagnetic waves and vice
- **Isotropic Radiator:**
- An isotropic radiator is a point source antenna which radiates equally in all the directions.
- All the points at distance "r" from the source lie on the surface of the sphere and have equal power densities.
- The electromagnetic waves spread uniformly in all the directions in space.
- The isotropic radiator is used for study the radiation patterns of other antennas.

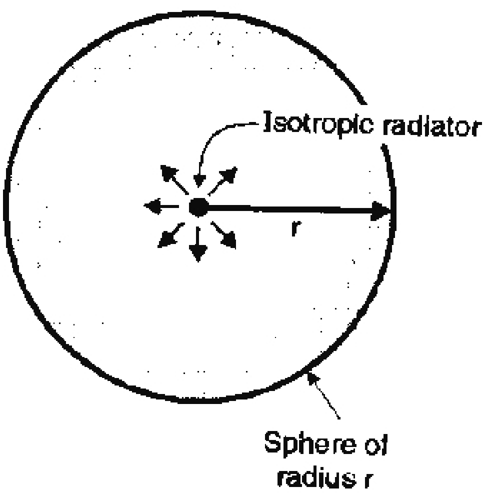


Figure 13.2 Isotropic radiator

Important Terms and Definitions:

- ***Radiation pattern of Antenna*:**
- A graph or diagram which tells us about the manner in which an antenna radiates power in different directions is known as the Radiation pattern of antenna.
- For a receiving antenna the diagram is known as the directional pattern of the antenna.

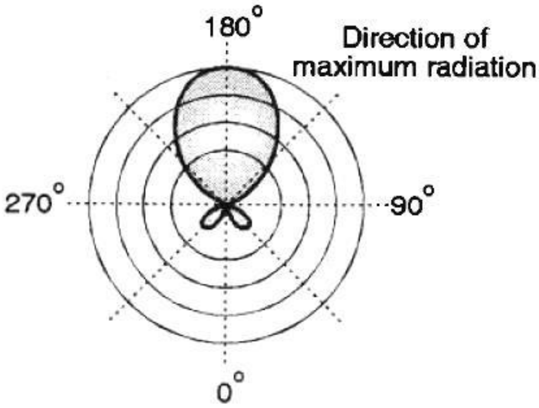


Figure 15.3 Radiation pattern of an antenna

- ***Directive Gain*:**
- The power gain of an antenna is defined as ratio of power fed to an isotropic antenna to the power fed to a directional antenna to develop the same field strength at the same distance, in the Direction of maximum radiation.
- ***Antenna Resistance*:**
- The antenna resistance has two components
    1. Radiation resistance
    2. Resistance due to the actual losses in the antenna
- ***Beam width of Antenna*:**
- Beam width of an antenna is defined as the frequency range over which the operation is satisfactory.
- It is the frequency difference between the half power points.
- There are two types of bandwidths. One is related to the radiation pattern and the other one is related to its input impedance.
- The angular separation between two 3 dB down points on the field strength of radiation pattern of antenna.
- Beam width is expressed in degrees.

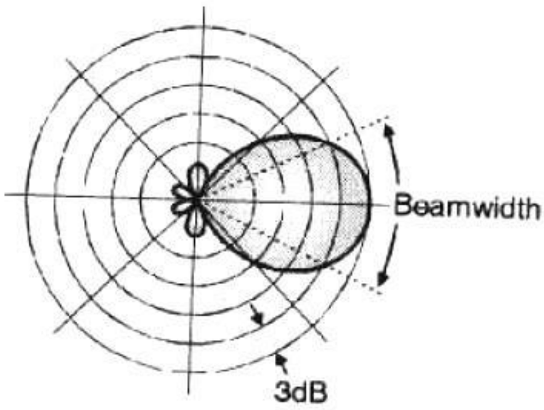


Figure 15.4 Beam width of antenna

Reflector Antenna / Parabolic Antenna

❖ The parabolic antenna is the form, which is most frequently used as the radar antenna. Figure, illustrates the parabolic antenna. A feed horn as a radiation source is placed at the focal point F that is known as the feed.

❖ The field leaves this feed horn with a spherical wave front. As each part of the wave front reaches the reflecting surface, it is shifted 180 degrees in phase and sent outward at angles that cause all parts of the field to travel in parallel paths.

❖ Because of the shape of a parabolic surface, all paths from F to the reflector and back are the same length. Due to these characteristics of parabolic it is most suitable for the microwave antenna. This ideal case may not happen in the practice.

❖ The parabolic antennas pattern has a conical form because of inaccuracies in the production more. This main lobe may vary in angular width from one or two degrees in some radar and it is up to 15 to 20 degrees in other radars.

❖ Very narrow beams are possible with this type of reflector. Its main application has been for tracking-radar antenna.

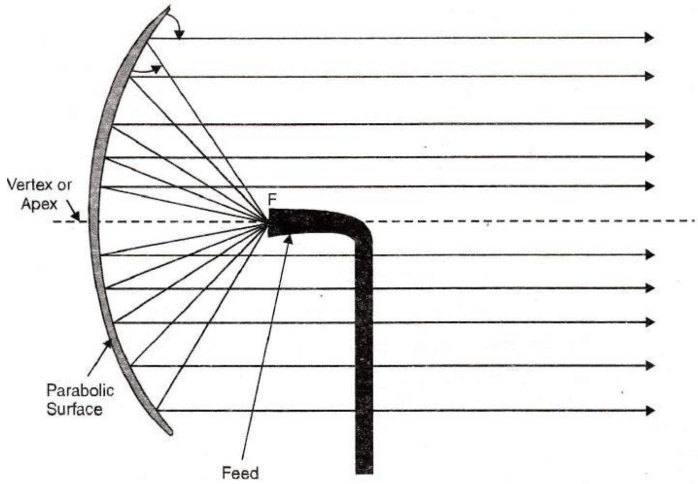


Figure 14.1 Parabolic Antenna

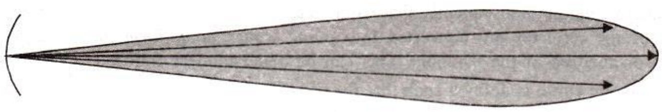


Figure 14.2 Radiation Pattern

❖ We know that an array of linear antennas can be employed to achieve a directional radiation pattern in which the radiated power is concentrated in a narrow beam. The same directivity objectives can also be achieved by the use of reflectors and lenses.

❖ Parabolic reflectors are employed when it is convenient to build antennas with apertures of many wavelengths. In case of parabolic reflectors, the surfaces are curved whereas the surface is plane in the antennas discussed previously.

❖ Arrays are commonly employed at lower frequencies. They are used up to about 1000 MHz although in special case they may be used up to 3,000 MHz Reflectors and lenses are more common above 1,000 MHz, although parabolic reflectors are sometimes employed at 100 MHz also. Lenses are basically microwave devices, not ordinarily used below 3000 MHz.

❖ In frequency region around 1000 MHz, tire choice between an array and a Paraboloidal reflector may sometimes be difficult. Arrays are employed when scanning by array phasing is desired whereas reflectors are employed when broad band operation or 1ow Noise temperature is desired. Sometimes a combination linear array feed and a parabolic cylinder reflector is employed.

- ❖ The principal advantage of lenses over reflector is that the feed and feed support structure do not block the aperture. This is because the rays are transmitted through the lenses rather than retained towards the feed.
- ❖ Since feed for lenses can be placed farther off the optical axis, they can also be employed in applications requiring all beam that can be moved regularly with respect to the axis. Further, permissible mechanical tolerances are somewhat greater for lenses than for reflectors.
- ❖ On the other hand, lenses are somewhat bulkier and expensive for the same gain and bandwidth as compared to reflectors. But these factors are less significant at very. Short wavelengths, above l0.000MHz-a region in which lenses are most commonly used.

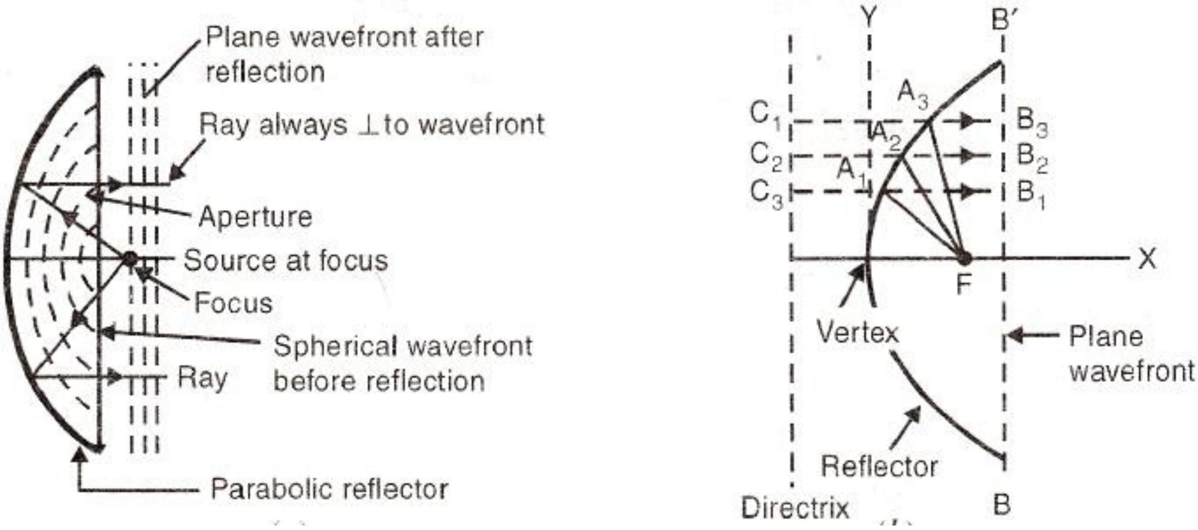
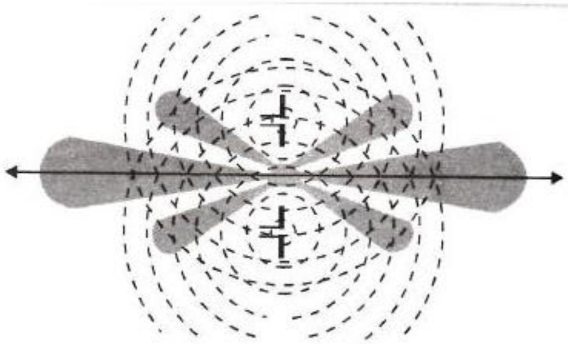


Figure 14.3 Parabolic Reflector Focusing Action

Phased Array Antenna



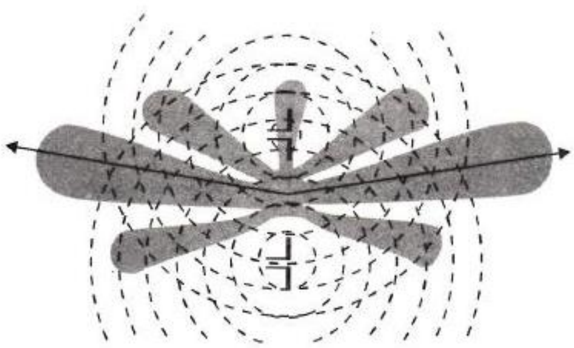


Figure 15.1 Two antenna elements, Fed with same phase

Figure 15.2 Two antenna elements, Fed with different phase

- ❖ In the Fig. 15.1, the signal is emitted (here therefore in the past) by 10 degrees phase shifted by the lower radiating element than of the upper radiating element. Because of this the main direction of the signal emitted together is moved up. (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. 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 that can be achieved for the Field of View (FOV) of a phased array antenna is 120^0 (60^0 left and 60^0 right).
- The following Fig. 15.2 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.
- A phased array antenna with a freely swivelling main direction is composed of a high number of radiating elements, and an electronic phase shifter is located after each radiating element. For example, the antenna of the RRP 117 consists of l584 radiating elements as shown in the Fig. 15.2.
- **Advantages of Array Antenna**
- The beam from an array can be rapidly scanned over the coverage of the using electronic scanning technique without moving the mechanical structure of the antenna. It can generate many independent beams from the same antenna.
- The array may generate fix beam, scanning beams or both at the same time. It can be used in monopoles tracking radar and conical scan tracking radar.
- More power may be obtained with separate transmitter at each of the elements of the array.
- It is much more suitable for a ship boomed or airborne radar because of steerable feature of an array.
- There is no spill over loss in array antenna, so the efficiency of an array antenna is slightly higher than that of other antenna.
- **Disadvantages of Array Antenna**
- The array antenna has the limited coverage from a single plane aperture.
- Cost and complexity are the biggest limitations of the array antenna.
- It is difficult to maintain phase stability under adverse operating

CHAPTER 4
CW AND FM RADAR

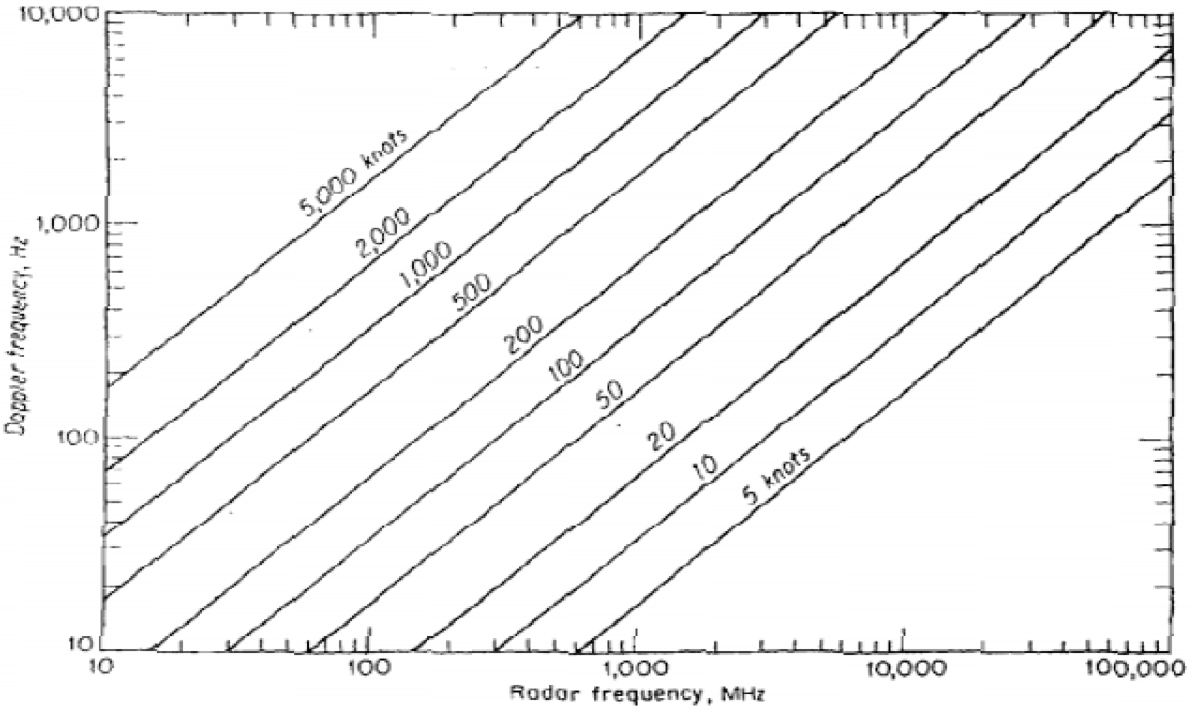
- **Doppler Effect**
- A radar detects the presence of objects and locates their position in space by transmitting electromagnetic energy and observing the returned echo. A pulse radar transmits a relatively short burst of electromagnetic energy, after which the receiver is turned on to listen for the echo.
- The echo not only indicates that a target is present, but the time that elapses between the transmission of the pulse and the receipt of the echo is a measure of the distance to the target.
- Separation of the echo signal and the transmitted signal is made on the basis of differences in time. The radar transmitter may be operated continuously rather than pulsed if the strong transmitted signal can be separated from the weak echo.
- The received-echo-signal power is considerably smaller than the transmitter power; it might be as little as 10^{-18} that of the transmitted power-sometimes even less. Separate antennas for transmission and reception help segregate the weak echo from the strong leakage signal, but the isolation is usually not sufficient.
- A feasible technique for separating the received signal from the transmitted signal when there is relative motion between radar and target is based on recognizing the change in the echo-signal frequency caused by the Doppler effect.
- It is well known in the fields of optics and acoustics that if either the source of oscillation or the observer of the oscillation is in motion, an apparent shift in frequency will result. This is the Doppler Effect and is the basis of CW radar.
- If R is the distance from the radar to target, tile total number of wavelengths λ contained in the two-way path between the radar and the target is 2R / λ.
- The distance R and the wavelength λ are assumed to be measured in the same units. Since one wavelength corresponds to an angular excursion of 2π radians, the total angular excursion φ made by the electromagnetic wave during its transit to and from the target is 4πR / λ radians.
- If the target is in motion, R and the phase φ are continually changing. A change in φ with respect to time is equal to a frequency.
- This is the Doppler angular frequency ω_d given by;

$$\therefore \omega_d = 2\pi f_d = \frac{d\phi}{dt}$$
$$\therefore \frac{4\pi}{\lambda}\frac{dR}{dt} = \frac{4\pi}{\lambda} v_r$$
$$\therefore f_d = \frac{2v_r}{\lambda} = \frac{2v_r f_0}{c}$$
$$\therefore f_d = 1.03 v_r / \lambda$$

- Where,

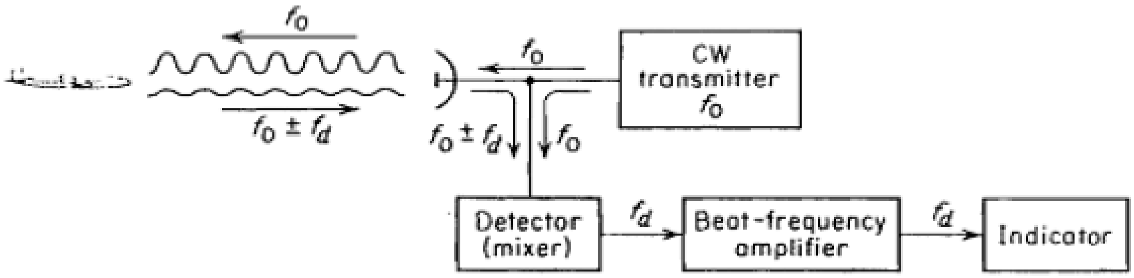
f_d = Doppler frequency shift
v_r = Relative velocity of target
λ = operating wavelength
c = velocity of EM wave

- A plot of this equation is shown in below figure.

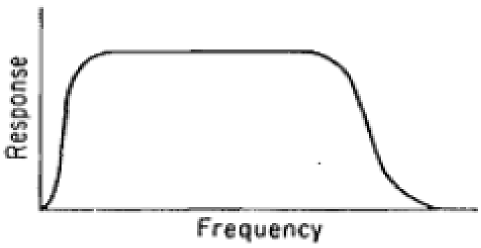


- ❖ The relative velocity may be written $v_r = v \cos \theta$, where v is the target speed and θ is the angle made by the target trajectory and the line joining radar and target. When θ = 0. The Doppler frequency is maximum. The Doppler is zero when the trajectory is perpendicular to the radar line of sight (θ = 90°).

CW Radar



(a)



(b)

Fig. 16.1 (a) Simple CW radar block diagram; (b) response characteristic of beat frequency Amplifier

- Consider the simple CW radar as illustrated by the block diagram of Fig. 16.1. The transmitter generates a continuous (unmodulated) oscillation of frequency fo, which is radiated by the antenna.
- A portion of the radiated energy is intercepted by the target and is scattered, some of it in the direction of the radar, where it is collected by the receiving antenna. If the target is in motion with a velocity *v*r, relative to the radar, the received signal will be shifted in frequency from the transmitted frequency *f*o by an amount ± fd as given by *fd* = 2**v*r / λ.
- The plus sign associated with the doppler frequency applies if the distance between target and radar is decreasing (closing target), that is, when the received signal frequency is greater than the transmitted signal frequency.
- The minus sign applies if the distance is increasing (receding target). The received echo signal at a frequency *f*0 ± *f*d enters the radar via the antenna and is heterodyned in the detector (mixer) with a portion of the transmitter signal *f*o to produce a doppler beat note of frequency *fd*. The sign of *fd* is lost in this process.
- The purpose of the doppler amplifier is to eliminate echoes from stationary targets and to amplify the doppler echo signal to a level where it can operate an indicating device. It might have a frequency-response characteristic similar to that of Fig. 16.1(b).
- The low-frequency cutoff must be high enough to reject tile d-c component caused by stationary targets, but yet it might be low enough to pass the smallest doppler frequency expected. Sometimes both conditions cannot be met simultaneously and a compromise is necessary. The upper cutoff frequency is selected to pass the highest doppler frequency expected.
- The indicator might be a pair of earphones or a frequency meter. If exact knowledge of the doppler frequency is not necessary, earphones are especially attractive provided the Doppler frequencies lie within the audio-frequency response of the ear. Earphones are not only simple devices. But the ear acts as a selective bandpass filter with a passband of the order of 50 Hz centred about the signal frequency.

- **Isolation between Transmitter and Receiver:-**

- Isolation between the transmitted and the received signals is achieved via separation in frequency as a result of the Doppler Effect.
- In practice, it is not possible to eliminate completely the transmitter leakage. However, transmitter leakage is not always undesirable.
- A moderate amount of leakage entering the receiver along with the echo signal supplies the reference necessary for the detection of the doppler frequency shift.
- There are two practical effects which limit the amount of transmitter leakage power which can be tolerated at the receiver. These are
    1. The maximum amount of power the receiver input circuitry can withstand before it is physically damaged or its sensitivity reduced (burnout) and
    2. The amount of transmitter noise due to hum, micro phonics, stray pick-up, and instability which enters the receiver from the transmitter.
- The additional noise introduced by the transmitter reduces the receiver sensitivity.
- The amount of isolation required depends on the transmitter power and the accompanying Transmitter noise as well as the ruggedness and the sensitivity of the receiver.
- The transmitter noise that enters the radar receiver via backscatter from the clutter is sometimes called **transmitted clutter.**

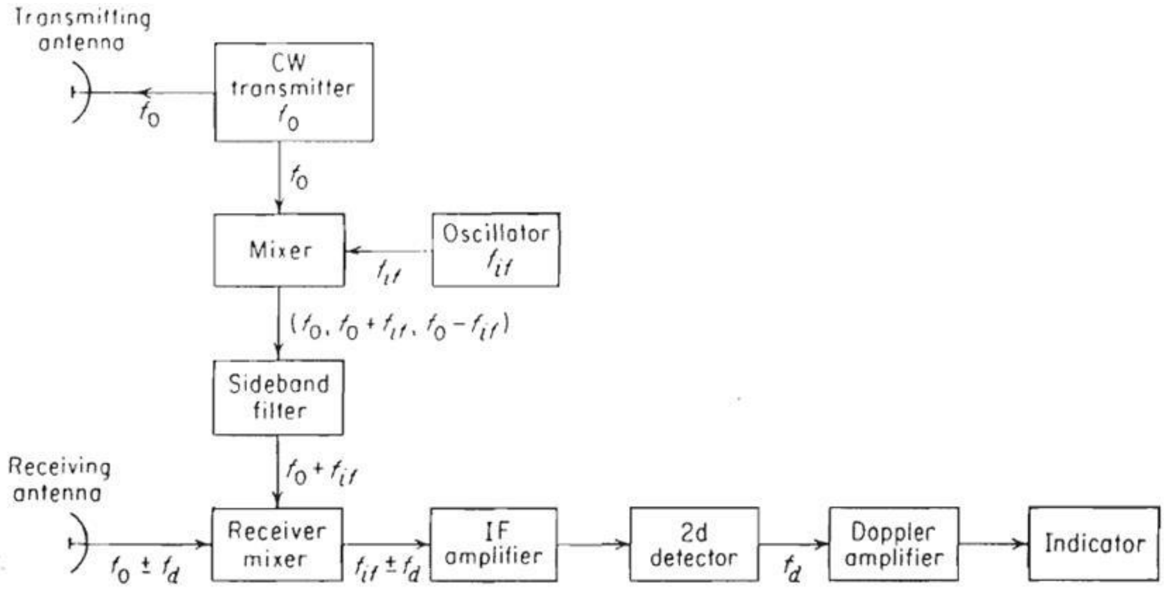


Figure 16.2. Block diagram of Doppler radar with IF receiver (sideband superheterodyne)

- CW type receivers are called homodyne receivers, or super heterodyne receivers with zero IF.
- The function of the local oscillator is replaced by the leakage signal from the transmitter.
- The simpler receiver is not as sensitive because of increased noise at the lower intermediate frequencies caused by **flicker effect.**
- Flicker-effect noise occurs in **semiconductor devices such as diode detectors and cathodes of vacuum tubes.**
- The noise power produced by the flicker effect varies as **1/f** $^{\alpha}$ where alpha is approximately unity.
- This is in contrast to shot noise or thermal noise, which is independent of frequency.
- Generally flicker noise would be high at lower freq.
- Due to flicker noise receiver sensitivity decreases.
- The effects of **flicker noise overcome** in the normal super heterodyne receiver by using an **intermediate frequency high enough, increase Tx power, or increase antenna aperture.**
- Instead of the usual local oscillator found in the conventional super heterodyne receiver, the local oscillator (or reference signal) is derived in the receiver from a portion of the transmitted signal mixed with a locally generated signal of frequency equal to that of the receiver IF.
- Since the output of the mixer consists of two sidebands on either side of the carrier plus higher harmonics, a narrowband filter selects one of the sidebands as the reference signal.
- The improvement in receiver sensitivity with an intermediate-frequency super heterodyne might be as much as 30 dB over the simple receiver.

- **Receiver Bandwidth:-**

- One of the requirements of the doppler-frequency amplifier in the simple CW radar or the IF amplifier of the sideband super heterodyne is that it be **wide enough to pass the expected range of doppler frequencies.**
- In most cases of practical interest the expected range of doppler frequencies will be much wider than the frequency spectrum occupied by the signal energy.

- The use of a wideband amplifier covering the expected doppler range will result in an increase in noise and a lowering of the receiver sensitivity.
- If the frequency of the doppler-shifted echo signal were known beforehand,
  1. A narrowband filter-one just wide enough to reduce the excess noise without eliminating a significant amount of signal energy-might be used.
  2. Also matched filter could be specified as per requirement.

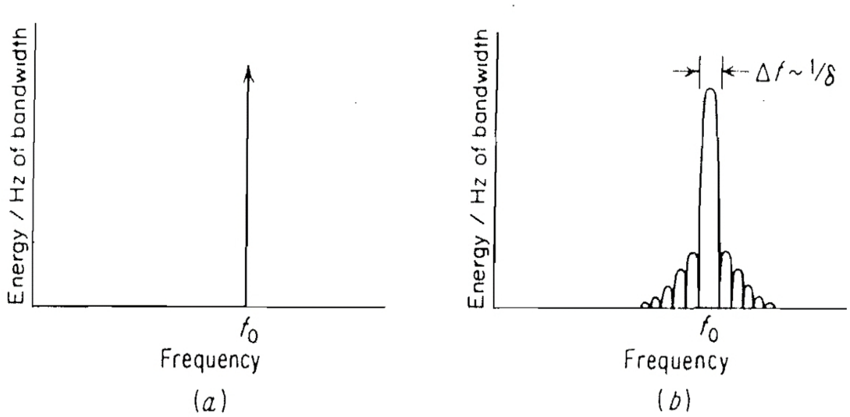


Figure 17.1. Frequency spectrum

- If the received waveform were a sine wave of infinite duration, its frequency spectrum would be a delta function (Fig. 17.1(a)) and the receiver bandwidth would be infinitesimal.
- But a sine wave of infinite duration and an infinitesimal bandwidth cannot occur in nature.
- The more normal situation is an echo signal which is a sine wave of finite rather than infinite duration.
- The frequency spectrum of a finite-duration sine wave has a shape of the form $\sin \pi(f - f_0)\Delta/\pi (f - f_0)$ where, f_0 and Δ are the frequency and duration of the sine wave, respectively, and f is the frequency variable over which the spectrum is plotted (Fig.17.1(b)).
- In many instances, the echo is not a pure sine wave of finite duration but is perturbed by fluctuations in cross section, target accelerations, scanning fluctuations, etc., which tend to broaden the bandwidth still further. Some of these spectrum-broadening effects are considered below.
- Assume a CW radar with an antenna beam width of Θ_B deg. scanning at the rate of Θ_s deg/s.
- The time on target (duration of the received signal) is $\Delta = \Theta_B / \Theta_s$ sec. Thus the signal is of finite duration and the bandwidth of the receiver must be of the order of the reciprocal of the time on target Θ_B / Θ_s.
- Although this is not an exact relation, it is a good enough approximation for purposes of the present discussion.
- If the antenna beam width were 2_0 and if the scanning rate were 36^0/s (6 rpm), the spread in the spectrum of the received signal due to the finite time on target would be equal to 18 Hz, independent of the transmitted frequency.
- If the target's relative velocity is not constant, a further widening of the received signal spectrum can occur. If a_r is the acceleration of the target with respect to the radar, the signal will occupy a bandwidth;

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

- **Doppler Filter Bank:-**

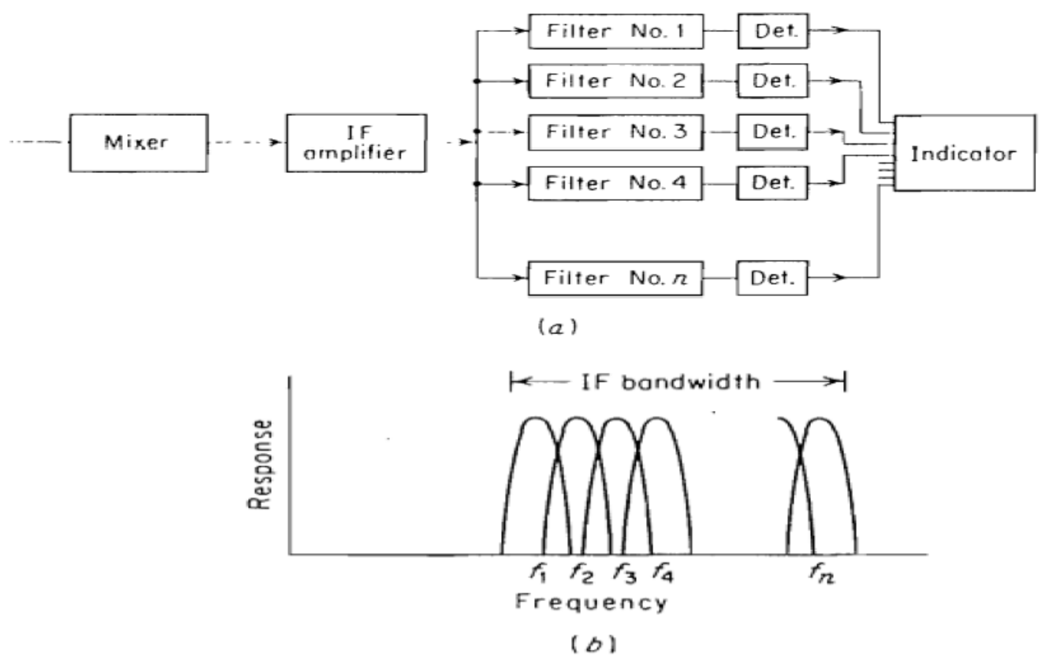


Figure 17.2. (a) Block diagram of IF Doppler filter bank; (b) frequency-response Characteristic of Doppler filter bank.

- A relative wide band of frequencies called as bank of narrowband filters are used to measure the frequency of echo signal.
- When the doppler-shifted echo signal is known to lie somewhere within a relatively wide band of frequencies, a bank of narrowband filters (Fig. 17.2) spaced throughout the frequency range permits a measurement of frequency and improves the signal-to noise ratio.
- The bandwidth of each individual filter is wide enough to accept the signal energy, but not so wide as to introduce more noise than need be. The centre frequencies of the filters are staggered to cover the entire range of doppler frequencies.
- If the filters are spaced with their half-power points overlapped, the maximum reduction in signal-to-noise ratio of a signal lies midway between adjacent channels compared with the signal-to-noise ratio at band is 3 dB.
- The more filters used to cover the band, the less will be the maximum loss experienced, but the greater the probability of false alarm.
- A bank of narrowband filters may be used after the detector in the video of the simple CW radar instead of in the IF.
- The improvement in signal-to-noise ratio with a video filter bank is not as good as can be obtained with an IF filter bank, but the ability to measure the magnitude of doppler frequency is still preserved. Because of fold over, a frequency which lies to one side of the IF carrier appears, after detection, at the same video frequency as one which lies an equal amount on the other side of the IF.
- Therefore the sign of the doppler shift is lost with a video filter bank, and it cannot be directly determined whether the Doppler frequency corresponds to an approaching or to a receding target. (The sign of the doppler may be determined in the video by other means, as described later.) One advantage of the fold over in the video is that only half the number of filters are required than in the IF filter bank.

❖ **Sign of Radial Velocity:-**

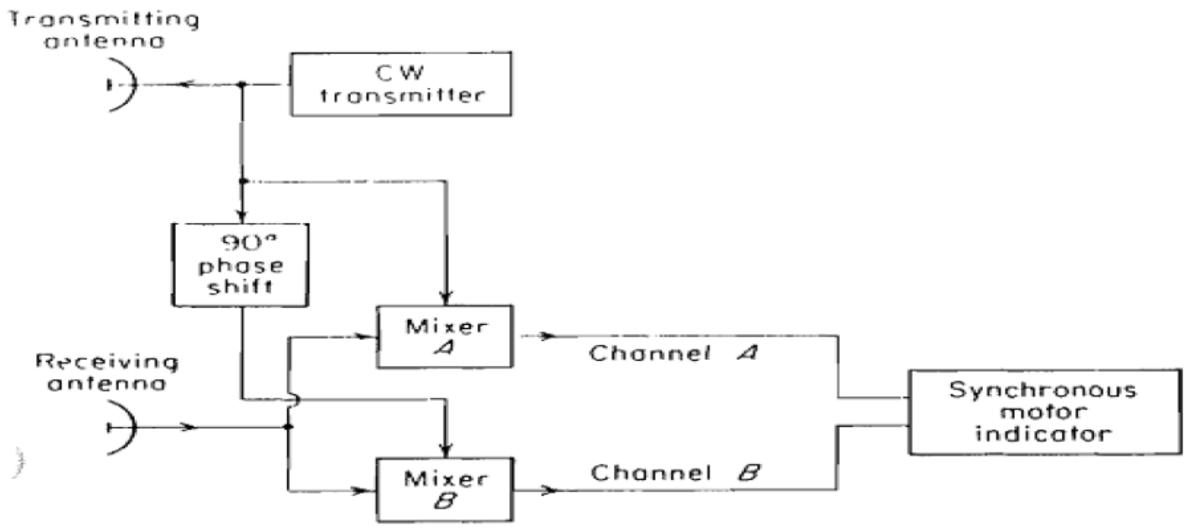


Figure 17.3. Measurement of Doppler direction using synchronous, two-phase motor

❖ The sign of the doppler frequency, and therefore the direction of target motion, may be found by splitting the received signal into two channels as shown in Fig. 17.3.

❖ In channel A the signal is processed as in the simple CW radar. The received signal and a portion of the transmitter heterodyne in the detector (mixer) to yield a difference signal

$$E_A = K_2 E_0 \cos(\pm w_d t + \varphi)$$

❖ Where,

E_A = amplitude of transmitter signal
K_2 = a constant determined from the radar equation
w_d = dopper angular frequency shift
φ = a constant phase shift, which depends upon range of initial detection

❖ The other channel is similar, except for a 90° phase delay introduced in the reference signal.

❖ The output of the channel B mixer is

$$E_B = K_2 E_0 \cos(\pm w_d t + \varphi + \pi/2)$$

❖ If the target is approaching (positive Doppler), the outputs from the two channels are

$$E_A(+) = K_2 E_0 \cos(w_d t + \varphi)$$
$$E_B(+) = K_2 E_0 \cos(w_d t + \varphi + \pi/2)$$

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

$$E_A(-) = K_2 E_0 \cos(w_d t - \varphi)$$
$$E_B(-) = K_2 E_0 \cos(w_d t - \varphi - \pi/2)$$

❖ The sign of wd and the direction of the target's motion may be determined according to whether the output of channel B leads or lags the output of channel A.

❖ One method of determining the relative phase relationship between the two channels is to apply the outputs to a synchronous two-phase motor. The direction of motor rotation is an indication of the direction of the target motion.

❖ **APPLICATION:-**

1. This technique has been described for a rate-of climb meter for vertical take-off aircraft to determine the velocity of the aircraft with respect to the ground during take-off and landing.
2. It has also been applied to the detection of moving targets in the presence of heavy foliage (leaves of plants).

- **The Doppler Frequency Shift:-**
- The expression for the doppler frequency shift given as below is approximate,

$$f_d = \frac{2v_r}{\lambda} = \frac{2v_r f_0}{c}$$

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

- Where,

  f^* =frequency from a target moving with a relative velocity v.
  f = transmitted frequency.

- **Application of CW Radar:-**

1. Measurement of the relative velocity of a moving target, as in the police speed monitor or in the rate-of-climb meter for vertical-take-off aircraft.
2. Suggested for the control of traffic lights, regulation of toll booths, vehicle counting, as a replacement for the “fifth-wheel" speedometer in vehicle testing, as a sensor in antilock braking systems, and for collision avoidance.
3. For railways, CW radar can be used as a speedometer
4. CW radar is also employed for monitoring the docking speed of large ships.
5. It has also seen application for intruder alarms and for the measurement of the velocity of missiles, ammunition, and baseballs.
6. In industry this has been applied to the measurement of turbine-blade vibration, the peripheral speed of grinding wheels, and the monitoring of vibrations in the cables of suspension bridges.
7. High-power CW radars for the detection of aircraft and other targets have been developed and have been used in such systems as the Hawk missile systems.

- **Drawback of CW Radar:-**

1. It cannot provide range of the target nor sense which particular cycle of oscillation is being received at any instant.

Frequency Modulated CW Radar (FMCW)

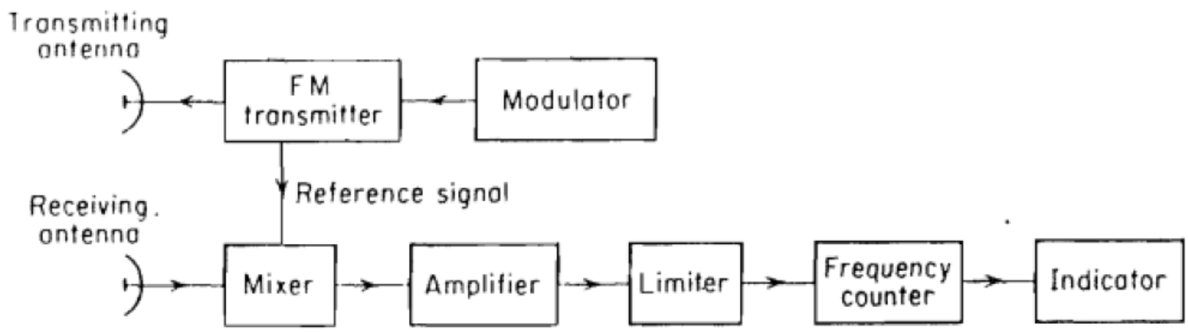


Figure 18.1. Block diagram of FMCW radar

- A portion of the transmitter signal acts as the reference signal required to produce the beat frequency. It is introduced directly into the receiver via a cable or other direct connection.
- Ideally the isolation between transmitting and receiving antennas is made sufficiently large so as to reduce to a negligible level the transmitter leakage signal which arrives at the receiver via the coupling between antennas.

- ❖ The beat frequency is amplified and limited to remove any amplitude fluctuations. The frequency of the amplitude-limited beat note is measured with a cycle-counting frequency meter calibrated in distance.

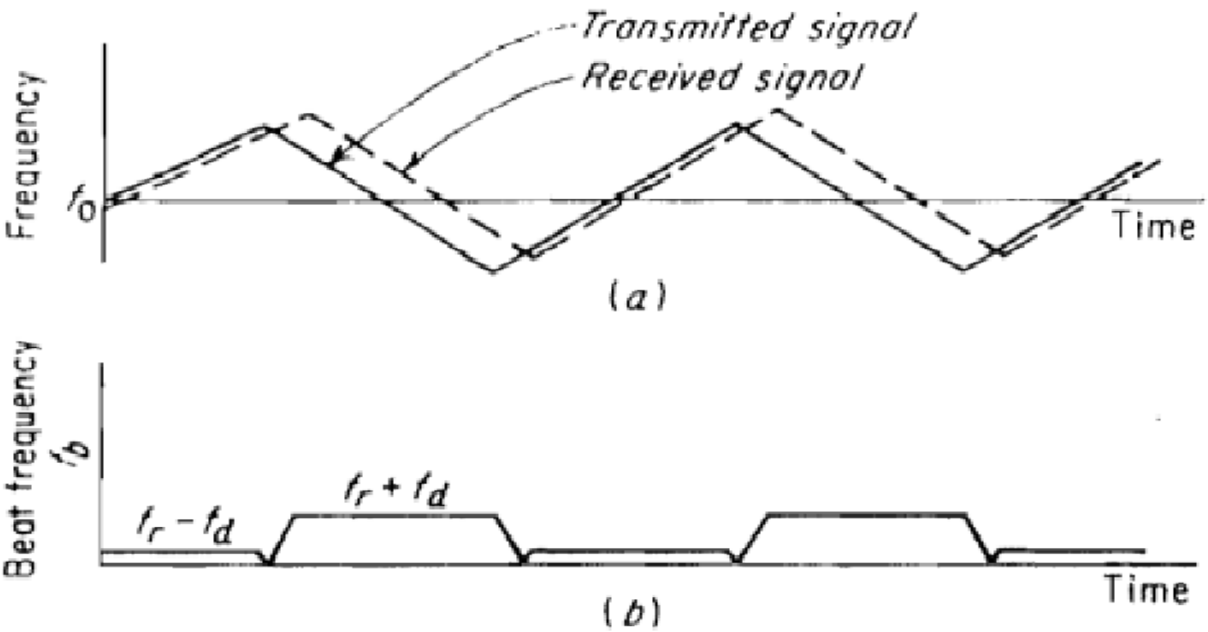


Figure 18.2. Frequency-time relation-ships in FM-CW radar when the fr + fd received signal is shifted in frequency by the doppler effect (a) Transmitted (solid curve) and echo (dashed curve); (b) beat frequency

- ❖ In the above, the target was assumed to be stationary. If this assumption is not applicable, a doppler frequency shift will be superimposed on the FM range beat note and an erroneous range measurement results.
- ❖ The doppler frequency shift causes the frequency-time plot of the echo signal to be shifted up or down (Fig. 18.2 (a)). On one portion of the frequency-modulation cycle the heat frequency (Fig, 18.2 (b)) is increased by the doppler shift, while on the other portion it is decreased.
- ❖ If for example, the target is approaching the radar, the beat frequency fb(up) produced during the increasing, or up, portion of the FM cycle will be the difference between the beat frequency due to the range f_r, and the doppler frequency shift f_d. Similarly, on the decreasing portion, the beat frequency, f_b(down) is the sum of the two.

  fb(up) = fr - fd

  fb(down) = fr + fd
- ❖ The range frequency fr, may be extracted by measuring the average beat frequency; that is,

  fr = 1/2[fb(up) + fb(down)]
- ❖ If fb(up) and fb(down) are measured separately, for example, by switching a frequency counter every half modulation cycle, one-half the difference between the frequencies will yield the doppler frequency. This assumes fr > fd.
- ❖ If, on the other hand, fr < fd such as might occur with a high-speed target at short range, the roles of the averaging and the difference-frequency measurements are reversed; the averaging meter will measure Doppler velocity, and the difference meter, range.
- ❖ If it is not known that the roles of the meters are reversed because of a change in the inequality sign between fr and fd an incorrect interpretation of the measurements may result.

- **Range and Doppler Measurement:-**
- The frequency-modulated CW radar (abbreviated as FM-CW), the transmitter frequency is changed as a function of time in a known manner. Assume that the transmitter frequency increases linearly with time, as shown by the solid line in Fig.18.3(a).

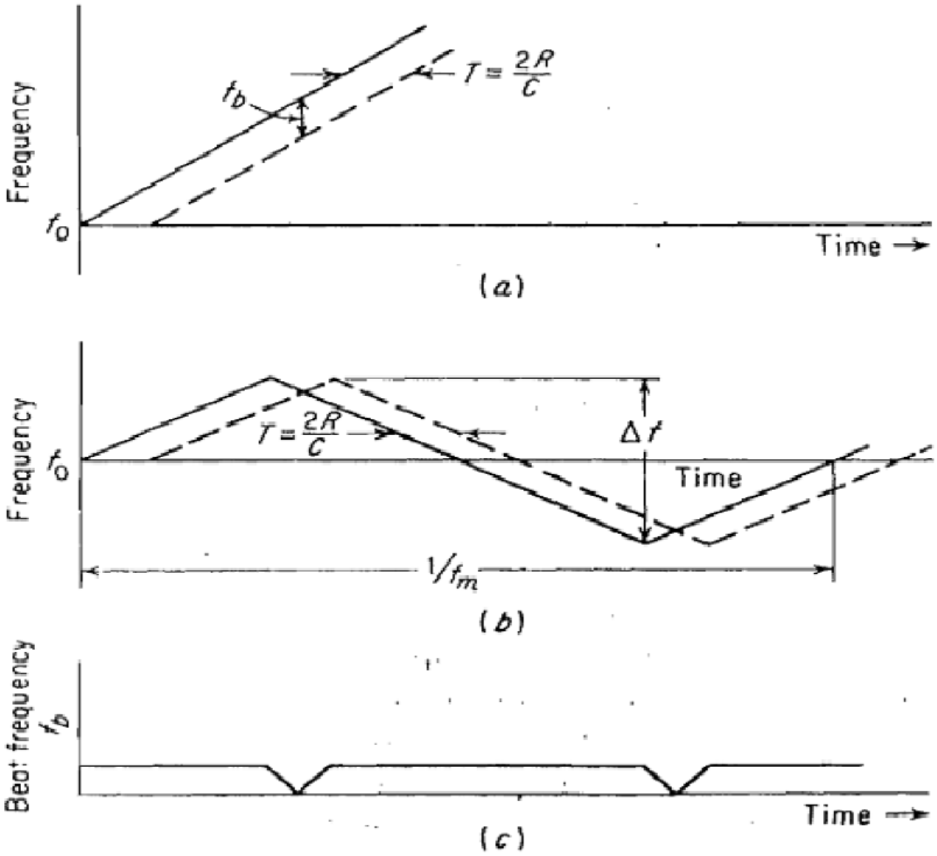


Figure 18.3. Frequency-time relationships in FM-CW radar. Solid curve represents transmitted signal, dashed curve represents echo. (a) Linear frequency modulation; (b) triangular frequency modulation; (c) beat note of (b)

- If there is a reflecting object at a distance R, an echo signal will return after a time T=2R/c. The dashed line in the figure represents the echo signal.
- If the echo signal is heterodyned with a portion of the transmitter signal in a nonlinear element such as a diode, a beat note f_b will be produced.
- If there is no doppler frequency shift, the beat note (difference frequency) is a measure of the target's range and $f_b = f_r$ where f_r is the beat frequency due only to the target's range.
- If the rate of change of the carrier frequency is f_0, the beat frequency is

$$f_r = f_0 T = 2 R f_0 / c$$

- In any practical CWradar, the frequency cannot be continually changed in one direction only. Periodicity in the modulation is necessary, as in the triangular frequency modulation waveform shown in Fig. 18.3(b).
- The modulation need not necessarily be triangular; it can be sawtooth, sinusoidal, or some other shape. The resulting beat frequency as a function of time is shown in Fig.18.3 (c) for triangular modulation.
- The beat note is of constant frequency except at the turn-around region. If the frequency is modulated at a rate f_m over a range Δf, the beat frequency is

$$f_r = 2 * 2 R f_m / c = 4 R f_m \Delta f / c$$

- Thus the measurement of the beat frequency determines the range R.

$$R = c f_r / 4 f_m \Delta f$$

❖ **FMCW Application:-**
1. Generally it is used only for single target.
2. It is used as an altimeter (it is not necessary to employ a linear modulation waveform) on board aircraft height above the ground

Delay Line Cancellers

❖ It act as a filter to eliminate the DC component of fixed target and pass the ac components of moving target.
❖ Two types of delay line cancellers;
1. Time domain filter / cancellers.
2. Freq. domain filter / cancellers.

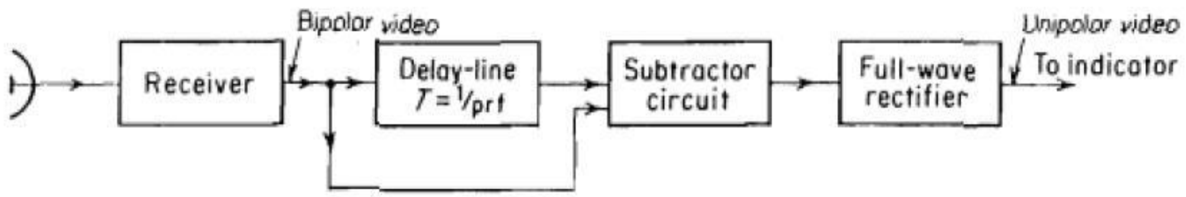


Figure 19.1. Block diagram of delay line cancellers

❖ The simple MTI delay-line canceler shown in Fig. 1 is an example of a time-domain filter. The capability of this device depends on the quality of the medium used is the delay line.
❖ The Pulse modulator delay line must introduce a time delay equal to the pulse repetition interval. For typical ground-based air-surveillance radars this might be several milliseconds.
❖ Delay times of this magnitude cannot be achieved with practical electromagnetic transmission lines. By converting the electromagnetic signal to an acoustic signal it is possible to utilize delay lines of a reasonable physical length since the velocity of propagation of acoustic waves is about 10^{-5} that of electromagnetic waves.
❖ After the necessary delay is introduced by the acoustic line, the signal is converted back to an electromagnetic signal for further processing.
❖ The use of digital delay lines requires that the output of the MTI receiver phase-detector be quantized into a sequence of digital words.
❖ The compactness and convenience of digital processing allows the implementation of more complex delay-line cancellers with filter characteristics not practical with analog methods.
❖ **One of the advantages of a time-domain delay-line canceller** as compared to the more conventional frequency-domain filter is that a single network operates at all ranges and does not require a separate filter for each range resolution cell.
❖ Frequency-domain doppler filter- banks are of interest in some forms of MTI and pulse doppler radar.
❖ A block diagram of delay line canceller is shown as fig. 1. The bipolar video from the phase detector modulates a carrier before being applied to the delay lines.
❖ The radar output is not directly applied to the delay lines as a video since it would be differentiated by the crystal transducer that convert the EM energy into acoustic energy, and vice-versa.
❖ The modulated bipolar video is divided between two channels. In one channel the signal is delayed by a PRF, while in the other channel it reaches directly i.e. undelayed.

- There is considerable attenuation in the signal introduced by the delay line and must be amplified in order to bring it back to its original level.
- Since the introduction of an amplifier into the delay channel can alter the phase of the delayed waveforms and introduce a line delay, an amplifier with the same delay characteristics is also used in the direct channel.
- An attenuator might also be interested in the direct channel to make equalizing voltage residue of the order of 1% or 40db.
- The output from the delayed and undelayed channels are detected to remove the carrier and then subtracted. The uncancelled bipolar video from the sub tractor is rectified in a full wave rectifier to obtain unipolar video signal for displaying on the PPI.
- The purpose of automatic balancing to detect any amplitude timing differences and generate AGC error voltage to adjust the amplifier gain and timing control error voltage to adjust the repetition frequency of the trigger generator.
- **Types of Delay Line Cancellers**

1. **Acoustic Delay Line**

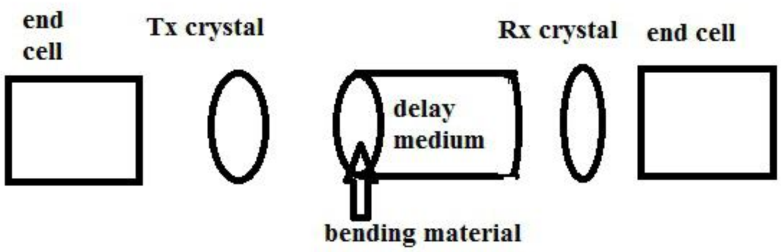


Figure 19.3. Elements of an acoustic delay line

- The basic elements of an acoustic delay line outlined in fig. 3. The EM energy is converted into acoustic energy by piezoelectric transmitting crystal. (Like transducer) and at the o/p side acoustic energy converted back into EM energy.

2. **Quartz Crystal**

- It has a high Q device with an inherently small bandwidth. However, when transducer is coupled to a delay medium, the medium has a damping effect, which broadens the bandwidth. Consequently, acoustic delay lines are relatively broadband device.

3. **Liquid Mercury**

- One of simplest acoustic delay lines consist of a straight cylindrical tube filled with liquid mercury. The transit time of acoustic waves in mercury at room temperature is approximately 17.5 us./inch.
- To produce a delay of 1000 us the line must be 57 inch in length exclusively of end cells. This is manageable size in ground-based radar.
- A more compact configuration may be had by folding the line back itself one or more times. Another method of obtaining a more compact delay line is of make use of multiple reflection in a tank filled with liquid.
- The alignment of the reflecting surface is a problem, and it has been difficult to obtain a leak proof construction.
- One of the disadvantages of either solid or liquid delay is the large insertion loss.

- **Multiple Frequency CW Radar (MFCW)**
- CW radar does not measure range, it is possible under some circumstances to do so by measuring the phase of the echo signal relative to the phase of the transmitted signal.
- The variation of phase with freq. is the fundamental basis of radar measurement of time delay or range measurement.
- It is easier to analysis the pulse radar and FMCW radar in term of time domain.
- The principal used in multiple freq. CW radar is the measurement of range by computing the phase difference.
- A measurement of range R of stationary target by employing continuous wave radar transmitting sine waves (2πft).
- The time taken by the sine wave is t=2R/c
- The o/p given by the phase detector, which will compare the transmitted signal on the received signal is written as,

$$\Delta\varphi = 2\pi ft$$
$$\Delta\varphi = 2\pi f\,(2R/c)$$
$$= 4\pi fR/c$$
$$R = c\Delta\varphi / 4\pi f$$
$$R = (\lambda / 4\pi)\Delta\varphi$$

- The maximum error occurs in measure net of phase difference is 2π radians.
- If we put the value $\Delta\varphi = 2\pi$ the maximum ambiguity, in range is,

$$R = (\lambda / 4\pi)\, 2\pi = \lambda / 2\pi$$

- Block diagram of multiple freq. CW radar is almost as CW radar except it has got one more channel and measuring device.
- The better accuracy in range measurement may be provided by the large freq. diff. between the two transmitted signals.
- Transmitting three or four freq. instead of just two can make more accurate measurement.
- The transmitted waveform is assumed to consist of two continuous sine waves of frequency f1 and f2 separated by an amount Δf.
- The voltage waveforms of the two components of the transmitted signal v_{1r} and v_{2r}, may be written as

$$v1r = \sin(2\pi f1\, t + \varphi 1)$$
$$v2r = \sin(2\pi f2\, t + \varphi 2)$$

- Where φ_1 and φ_2 are arbitrary (constant) phase angles.
- The echo signal is shifted in frequency by the Doppler Effect. The form of the Doppler shifted signals at each of the two frequencies *f1* and *f2* may be written as;

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

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

- Where,

  Ro = range to target at a particular time t = t0 (range that would be measured if target were not moving)
  fd1 = doppler frequency shift associated with frequency *f1*
  fd2 = doppler frequency shift associated with frequency *f2*

- The receiver separates the two components of the echo signal, each received signal component with the corresponding transmitted waveform and extracts the two Doppler frequency components given below:

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

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

- The phase difference between these two components is

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

- Hence,

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

- A large difference in frequency between the two transmitted signals improves the accuracy.

$$R_{\text{unamb}} = \frac{c}{2\ \Delta f}$$

- The two-frequency CW radar is essentially a single-target radar since only one phase difference can be measured at a time.
- If more than one target is present, the echo signal becomes complicated and the meaning of the phase measurement is doubtful.
- The theoretical rms range error is ,

$$\delta R = \frac{c}{4\pi\ \Delta f (2E/N_0)^{1/2}}$$

- Where,

  E = energy contained in received signal
  N_0 = noise power per Hz of bandwidth
- **Application of Multi Frequency CW Radar:-**
  1. Useful for satellite or space tracking.
  2. It may be used for missile guidance and surveying.

CHAPTER 5
MTI & PULSE DOPPLER RADAR

- ## Introduction
- The radars discussed till now were required to detect target in the presence of noise. But in practical radar have to deal with more than receiver noise when detecting target while they can also receive echoes from the natural environment such as land, sea, weather etc.
- These echoes are called clutter, since they tend to clutter the radar display with unwanted information's.
- Clutter echoes signal has greater magnitude then echo signal receives from the aircraft.
- When an aircraft echo and a clutter echo appear in the same radar resolution cell, the aircraft might not be detected.
- But the Doppler effect permits the radar to distinguish moving target in the presence of fixed target even the echoes signal from fixed has comparatively than the moving target such as aircraft.
- ## MTI Radar (Principle)
- **MTI radar with power amplifier transmitter**
- 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)

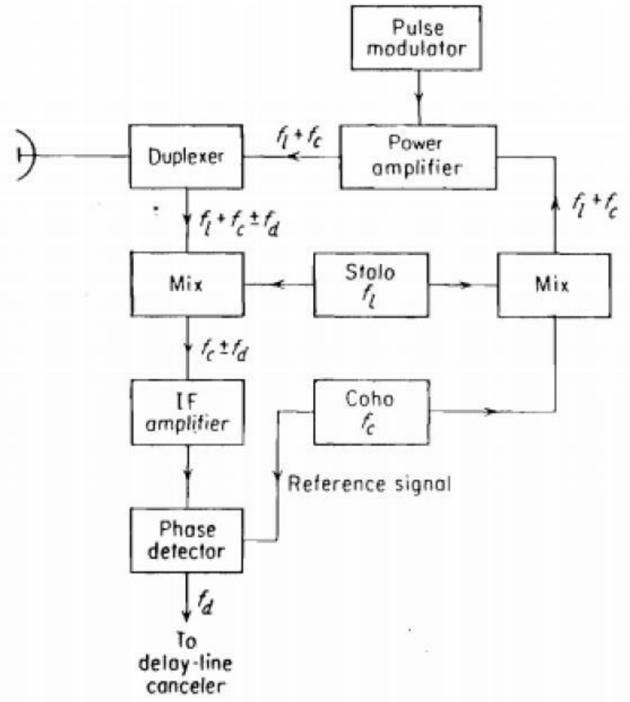


Figure 21.1. Block diagram of MTI radar with power amplifier transmitter

- The block diagram of MTI radar employing a power amplifier is shown in Fig. 21.1. 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. 21.1, 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 super heterodyne 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.
- The characteristic feature of coherent MTI radar is that the transmitted signal must be coherent (in phase) with the reference signal in the receiver. The function of the stalo is to provide the necessary frequency translation from the IF to the transmitted (RF) frequency.
- Although the phase of the stalo influences the phase of the transmitted signal, any stalo phase shift is cancelled on reception because the stalo that generates the transmitted signal also acts as the local oscillator in the receiver.
- The reference signal from the coho and the IF echo signal are both fed into a mixer called the pulse detector The phase detector differs from the normal amplitude detector since its output is proportional to the phase difference between the two input signals.
- Any one of a number of transmitting-tube types might be used as the power amplifier. These include the triode, tetrode, klystron, traveling-wave tube, and the crossed-field amplifier.
- **MTI radar with power oscillator transmitter**

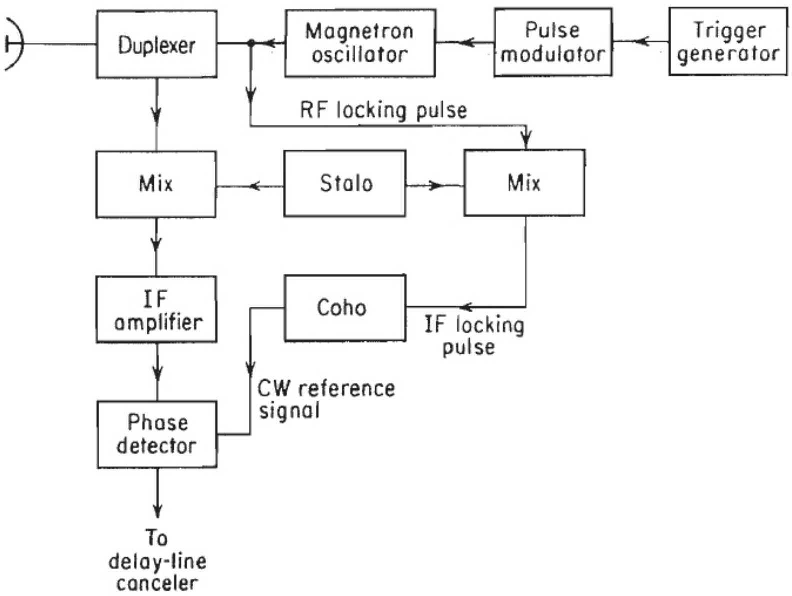


Figure 21.2. Block diagram of MTI radar with power oscillator transmitter

- A block diagram of MTI radar using a power oscillator is shown in Fig. 21.2. A portion of the transmitted signal mixed with the STALO output to produce an IF beat signal whose phase is directly related to the phase of the phase of the transmitter.
- This IF pulse is applied to the coherent (COHO) and cause the phase of the COHO CW oscillation to “lock” in step with the phase of the IF reference pulse.
- The phase of the COHO is then related to the phase of the transmitted pulse and may be used as the reference signal for echoes received from the particular transmitted pulse.
- Upon the next transmission another IF locking pulse is generated relocks the phase of CW COHO until the next locking pulse comes along.

❖ "BUTTERFLY" Effect in MTI Radar

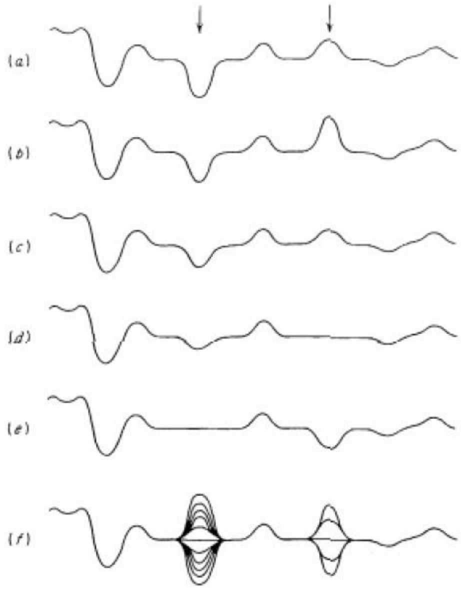


Figure 21.3. (a-e) Successive sweeps of an MTI radar A-scope display (echo amplitude as a function of time); (f) superposition of many sweeps; arrows indicate position of moving targets

- ❖ Moving targets may be distinguished from stationary targets by observing the video output on an A-scope (amplitude vs. range). A single sweep on an A-scope might appear as in Fig. 21.3 (a).
- ❖ This sweep shows several fixed targets and two moving targets indicated by the two arrows. On the basis of a single sweep, moving targets cannot be distinguished from fixed targets. (It may be possible to distinguish extended ground targets from point targets by the stretching of the echo pulse. However, this is not a reliable means of discriminating moving from fixed targets since some fixed targets can look like point targets, e.g., a water tower. Also, some moving targets such as aircraft flying in formation can look like extended targets.)
- ❖ Successive A scope sweeps (pulse-repetition intervals) are shown in Fig. 21.3 (b) to (e). Echoes from fixed targets remain constant throughout but echoes from moving targets vary in amplitude from sweep to sweep at a rate corresponding to the Doppler frequency.
- ❖ The superposition of the successive A-scope sweeps is shown in Fig. 21.3(J). The moving targets produce, with time, a butterfly effect on the A-scope.

❖ Delay Line Cancellers

- ❖ It act as a filter to eliminate the DC component of fixed target and pass the ac components of moving target.
- ❖ Two types of delay line cancellers;
    1. Time domain filter / cancellers.
    2. Freq. domain filter / cancellers.

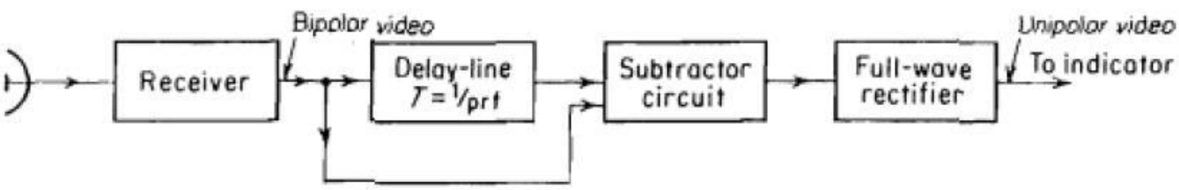


Figure 22.1. Block diagram of delay line cancellers

- The simple MTI delay-line canceler shown in Fig. 22.1 is an example of a time-domain filter. The capability of this device depends on the quality of the medium used is the delay line.
- The Pulse modulator delay line must introduce a time delay equal to the pulse repetition interval. For typical ground-based air-surveillance radars this might be several milliseconds.
- Delay times of this magnitude cannot be achieved with practical electromagnetic transmission lines. By converting the electromagnetic signal to an acoustic signal it is possible to utilize delay lines of a reasonable physical length since the velocity of propagation of acoustic waves is about 10^{-5} that of electromagnetic waves.
- After the necessary delay is introduced by the acoustic line, the signal is converted back to an electromagnetic signal for further processing.
- The use of digital delay lines requires that the output of the MTI receiver phase-detector be quantized into a sequence of digital words.
- The compactness and convenience of digital processing allows the implementation of more complex delay-line cancellers with filter characteristics not practical with analog methods.
- **One of the advantages of a time-domain delay-line canceller** as compared to the more conventional frequency-domain filter is that a single network operates at all ranges and does not require a separate filter for each range resolution cell.
- A block diagram of delay line canceller is shown as fig. 1. The bipolar video from the phase detector modulates a carrier before being applied to the delay lines.
- The radar output is not directly applied to the delay lines as a video since it would be differentiated by the crystal transducer that convert the EM energy into acoustic energy, and vice-versa.
- The modulated bipolar video is divided between two channels. In one channel the signal is delayed by a PRF, while in the other channel it reaches directly i.e. undelayed.
- There is considerable attenuation in the signal introduced by the delay line and must be amplified in order to bring it back to its original level.
- Since the introduction of an amplifier into the delay channel can alter the phase of the delayed waveforms and introduce a line delay, an amplifier with the same delay characteristics is also used in the direct channel.
- An attenuator might also be interested in the direct channel to make equalizing voltage residue of the order of 1% or 40db.
- The output from the delayed and undelayed channels are detected to remove the carrier and then subtracted. The uncancelled bipolar video from the sub tractor is rectified in a full wave rectifier to obtain unipolar video signal for displaying on the PPI.
- The purpose of automatic balancing to detect any amplitude timing differences and generate AGC error voltage to adjust the amplifier gain and timing control error voltage to adjust the repetition frequency of the trigger generator.
- **Types of Delay Line Cancellers**
    1. **Acoustic Delay Line**

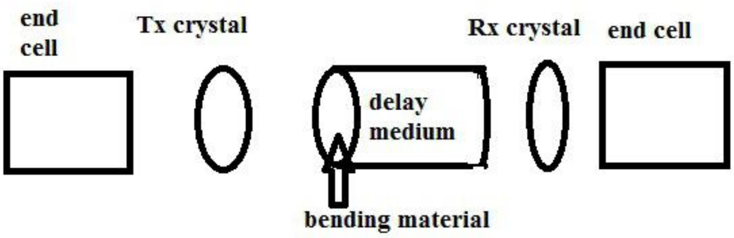


Figure 19.3. Elements of an acoustic delay line

- The basic elements of an acoustic delay line outlined in fig. 3. The EM energy is converted into acoustic energy by piezoelectric transmitting crystal. (Like transducer) and at the o/p side acoustic energy converted back into EM energy.

4. Quartz Crystal

- It has a high Q device with an inherently small bandwidth. However, when transducer is coupled to a delay medium, the medium has a damping effect, which broadens the bandwidth. Consequently, acoustic delay lines are relatively broadband device.

5. Liquid Mercury

- One of simplest acoustic delay lines consist of a straight cylindrical tube filled with liquid mercury. The transit time of acoustic waves in mercury at room temperature is approximately 17.5 us./inch.
- To produce a delay of 1000 us the line must be 57 inch in length exclusively of end cells. This is manageable size in ground-based radar.
- A more compact configuration may be had by folding the line back itself one or more times. Another method of obtaining a more compact delay line is of make use of multiple reflection in a tank filled with liquid.
- The alignment of the reflecting surface is a problem, and it has been difficult to obtain a leak proof construction.
- One of the disadvantages of either solid or liquid delay is the large insertion loss.

Response of the Delay Line Canceller (Filter Characteristics)

- Filter characteristics of the delay-line canceller. The delay-line canceller acts as a filter which rejects the d-c component of clutter. Because of its periodic nature, the filter also rejects energy in the vicinity of the pulse repetition frequency and its harmonics.
- The video signal received from a particular target at a range R0 is

$$\mathbf{V_1 = k \sin (2\pi f_d t - \varphi_0)}$$

- Where,

  $\varphi 0$ = phase shift

  k = amplitude of video signal.

- The signal from the previous transmission, which is delayed by a time T = pulse repetition interval, is

$$\mathbf{V_2 = k \sin (2\pi f_d(t - T) - \varphi_0)}$$

- Everything else is assumed to remain essentially constant over the interval T so that k is the same for both pulses. The output from the sub tractor is

$$\mathbf{V = V_1 - V_2 = 2 * k \sin \pi f_d T \cos [2\pi f_d(t - T / 2) - \varphi_0]}$$

- It is assumed that the gain through the delay-line canceller is unity. The output from the canceller V consists of a cosine wave at the doppler frequency f_d with an amplitude 2*k sin $\pi f_d T$.
- Thus the amplitude of the canceled video output is a function of the Doppler frequency shift and the pulse-repetition interval, or PRF.
- The magnitude of the relative frequency-response of the delay-line canceller [ratio of the amplitude of the output from the delay-line canceller, 2*k sin $\pi f_d T$, to the amplitude of the normal radar video kj is shown in Fig. 23.1

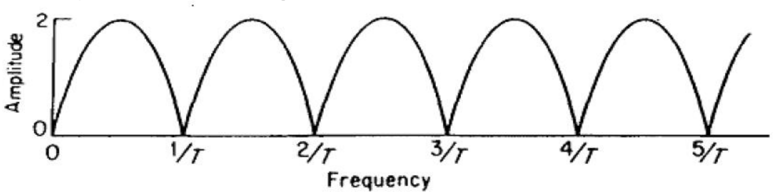


Figure 23.1. Frequency response of single delay line cancellers

❖ Double Delay Line Canceller

- The frequency response of a single-delay-line canceller does not always have as broad clutter-rejection null as might be desired in the vicinity of d-c. The clutter-rejection notches may be widened by passing the output of the delay-line canceller through a second delay-line canceller as shown in Fig. 23.2. The output of the two single-delayline cancellers in cascade is the square of that from a single canceller.
- Thus the frequency response is4 sin2 πfdT. The configuration of Fig. 23.2 is called a double-delay-line canceller, or simply a double canceller. The relative response of the double canceller compared with that of a single delay line canceller is shown in Fig. 23.3.
- The finite width of the clutter spectrum is also shown in this figure so as to illustrate the additional cancellation of clutter offered by the double canceller.
- The two-delay-line configuration of Fig. 23.2 has the same frequency-response characteristic as the double-delay-line canceller. The operation of the device is as follows. Signal f (t) is inserted into the adder along with the signal from the preceding pulse period, with its amplitude weighted by the factor - 2, plus the signal from two pulse periods previous. The output of the adder is therefore

f(t) – 2f(t + T) + f(t + 2T)

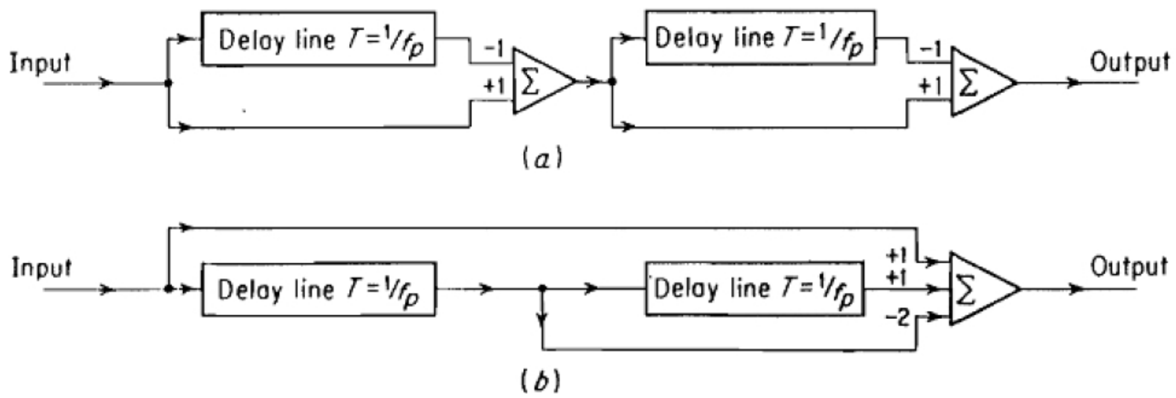


Figure 23.2. (a) Double delay line canceller (b) Three pulse canceller

- Which is the same as the output from the double-delay-line canceller

f(t) – f(t + T) - f(t + T) + f(t + 2T)

- This configuration is commonly called the three-pulse canceller.

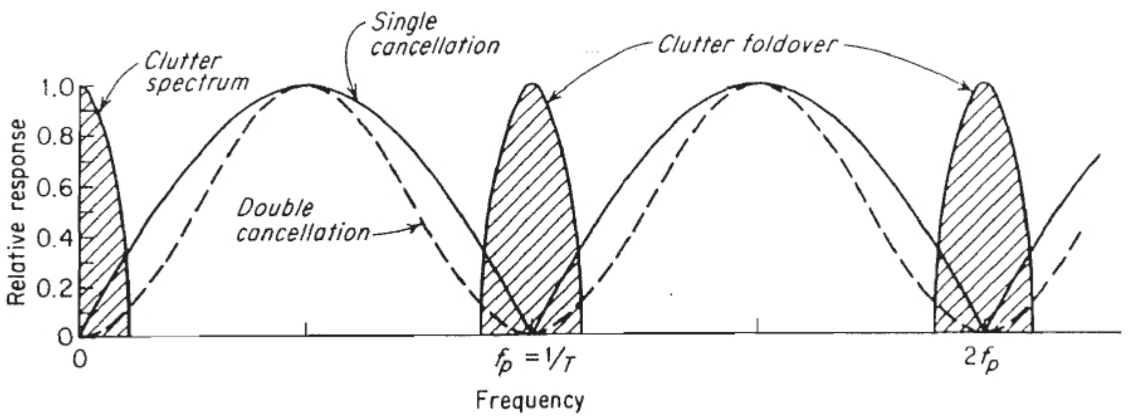


Figure 23.3. Frequency response of single & double delay line canceller

- **Blind Speed**
- The response of the single-delay-line canceller will be zero whenever the argument $\pi f_d T$ in the amplitude factor of $V = V1 - V2 = 2*k \sin \pi f_d T \cos [2\pi f_d(t - T / 2) - \varphi 0]$ is 0, π, 2π,..., etc., or when $f_d = n / T = n f_p$
- Where,

  n = 0, 1, 2, …

  fp = pulse repetition frequency.
- The delay-line canceller not only eliminates the d-c component caused by clutter (n = 0), but unfortunately it also rejects any moving target whose doppler frequency happens to be the same as the PRF or a multiple thereof. Those relative target velocities which result in zero MTI response are called blind speeds and are given by;

$$V_n = n\lambda / 2T = n\lambda f_p / 2$$

- Where,

  V_n is the n_{th} blind speed.
- If λ is measured in meters, fp in Hz, and the relative velocity in knots, the blind speeds are;

$$V_n = n\lambda f_p / 1.02$$

- The blind speeds are one of the limitations of pulse MTI radar which do not occur with CW radar. They are present in pulse radar because doppler is measured by discrete samples (pulses) at the PRF rather than continuously. If the first blind speed is to be greater than the maximum radial velocity expected from the target, the product λfp must be large.

- **Multiple or Staggered Pulse Repetition Frequencies**
- If a radar is operating at multiples PRFs or its PRF is changed either pulse to pulse or scan to scan, than the effect of blind speed can be eliminated from the radar. If two radar operating at same frequencies but having its different PRF then if one radar is blind to moving target.
- So, if we use single radar but having different PRF than the same affect can be achieved. When the PRF is changing pulse to pulse than it may be called as staggered PRF. Staggering of PRF is generally employed in Air Traffic Control Radar such as Surveillance Radar Element (SRE).

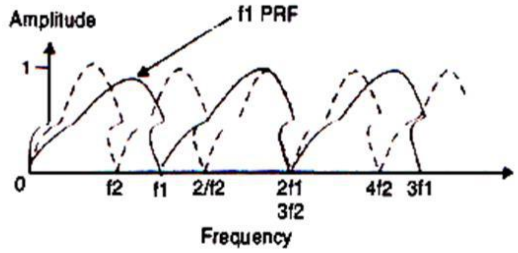


Figure 24.1. Frequency response of two PRF

- In the Fig. 24.1 above the frequency response of two PRF is shown. Suppose the first PRF is F1 shown in bold line and the speed of second PRF is F2 shown in dotted lines. If we observed the figure, it is clear that at particular position when 2f1=3f2, both the PRFs have the same blind speed.
- The multiples PRFs can be obtained by using several methods. Using the following techniques may vary the PRFs:
  1. Pulse to pulse (known as staggered PRF)
  2. Scan to scan
  3. Dwell to dwell.

- The problems occur in using staggered PRF is that residual of unconcealed echoes of clutters, which are due to second time around echoes. So to minimize the second time around echoes affect, if we use unstaggered PRF in the sector where second time around are expected more and rest of the sector used staggered PRFs.
- **Sub Clutter Visibility:**
- Sub clutter visibility may be defined as the ability of MTI radar to detect the moving target, if the target is superimposed over the clutters. SCV defined the performance of an MTI radar and it is measured in dbs. It may be defined as

SCV = the gain in signal-to clutter power ratio.

- Suppose an MTI radar has SCV 20 dB than it means that a moving target can be detected in the presence of clutter even though the clutter echo power is 100 times the target echo power.
- **The Cancellation Ratio:**
- The cancellation ratio may be defined as the ratio of a fixed target signal voltage using MTI cancellation to signal voltage without MTI cancellation. We may write

$$Cancellation\ ratio = \frac{fixed\ targets\ signal\ voltage\ after\ MTI\ cancellation}{Signal\ voltage\ without\ MTI\ cancellation}$$

- The CR is a number that is always less than One (1) and may be expressed in db.
- **The Target Visibility Factor**:
- The target visibility factor is the ratio of the signal strength from a target, which is moving at a specified radial velocity to the signal strength from the same target when it is moving at an optimum radial velocity.

Range gated Doppler Filters

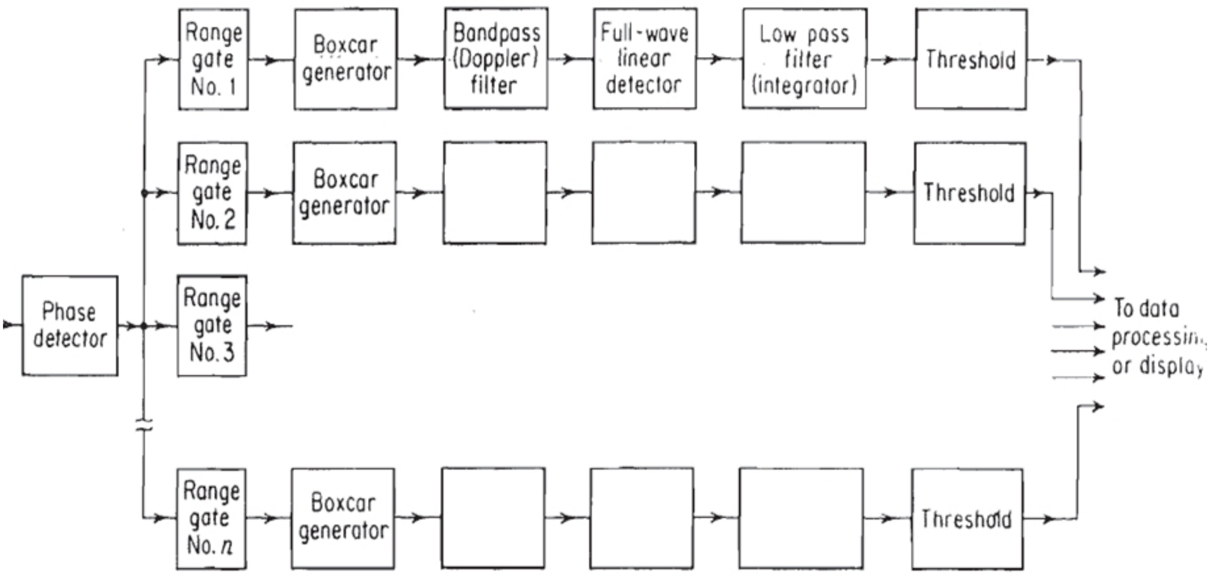


Figure 24.2. Block diagram of MTI radar using range gated filter

- In order to separate moving targets from stationary clutter, the delay line canceller has been widely used in MTI radar. Quantizing the time in to small interval can eliminate the loss of range information and collapsing loss. This process is known as the range gating where width depends on range accuracy desired. After quantizing the radar return interval, the output from each gate is applied to narrow band filter.

- ❖ A block diagram of the video of an MTI radar using multiple range gates followed by clutter rejection filter is shown in Fig. Here the range gates sample the output of the phase detector sequentially range interval.
- ❖ Each range open in sequence just long enough to sample the voltage of the video waveform corresponding to a different range interval in space or it acts as a switch/gate which open and close at a proper time.
- ❖ The output of the range gate is given to a circuit known as box car generator. Its function is to aid in the filtering and detection process enhancing the fundamental of the modulation frequency and eliminating harmonics of the PRF.
- ❖ The clutter rejection filter is nothing but a band pass filter whose bandwidth depends on the extent of the excepted clutter spectrum. The filtered output from the Doppler filter is further fed to a full wave linear detector which convert the bipolar video.
- ❖ A low pass filter or integrator passes these unipolar video to the threshold detection circuit. Any signal crosses the threshold level is treated as a target. The outputs from each range channels are combined for display on the PPI or any other display unit.

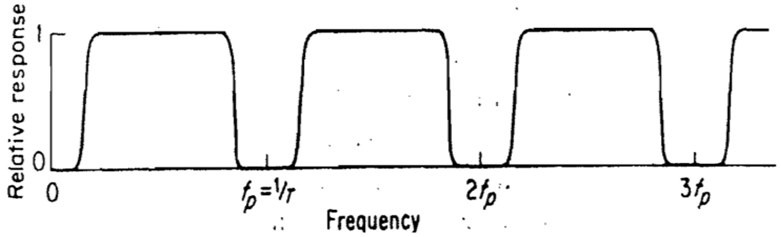


Figure 24.3.Frequencu response characteristics of range gated filter

- ❖ The presentation of this type of MTI radar is far better than the display from normal MTI radar.
- ❖ The frequency response characteristics of an MTI radar using range gates and filter is shown in fig. the shape of the rejection band is mainly determined by the shape of the band pass filter.
- ❖ It must be pointed out that the MTI radar using range gates and filters is more complex than an MTI with single delay line canceller a better MTI performance is achieved from a better match between clutter filter characteristics and clutter spectrum.

Digital Signal Processor

- ❖ In the radar system MTI signal processing to be done in the receiver. The received echoes signals either from the target or from the clutter are to be processed in such a manner that at the display unit only moving targets to be available. The signal strength should be good enough to display the target without introducing any noise over the scope.
- ❖ Earlier, in an MTI processing we were using analog delay lines, it was rare for an MTI radar to employs more two analog delay lines. The rapid development of digital technology brought the revolution in the radar technology also. Digital technique allowed radar designer to use memory as a digital storage device, in that delay can be obtained for whatever length of time was required.
- ❖ The advantages offered by digital MTI process include removing of blind phase in MTI radar by using I and Q channel. When the phase between the Doppler signal and the sampling at the PRF results in a loss, it is called a blind phase. It is different from the blind speed.

`

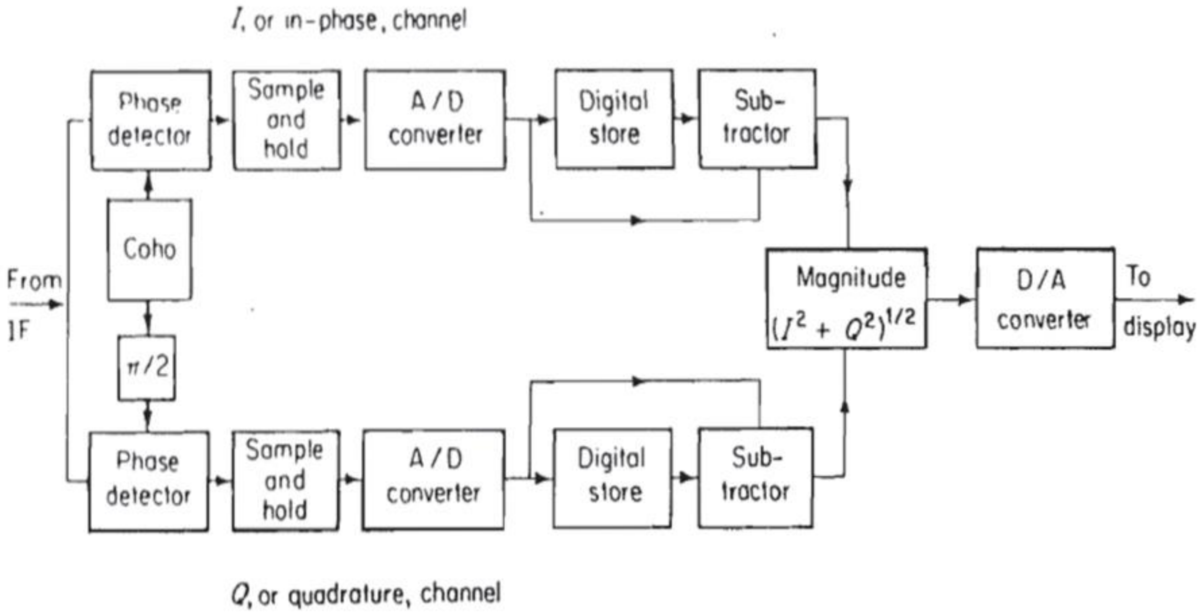


Figure 24.4. Block diagram of digital signal processor

- ❖ A block diagram of digital MTI Doppler signal processor is as shown in fig. the output from the IF amplifier is split in to two channels, one for in phase channel doted "I" and the other for quadrature channel denoted by "Q" and given to the respective phase detector.
- ❖ The outputs of the phase detectors are 90 degree out of phase to each other. The Q channel eliminates the effect of blind phases. Following the phase detector the bipolar video signal is sampled within each range resolution cell. These voltage samples are converted to a series of digital words by using A/D converter. In a digital memory, the digital words are being delayed for one PRP.
- ❖ Further signals are then subtracted from the digital words of the successive sweep. By taking the square root of (I2 + Q2). The digital outputs of the I and Q channels are combined. This also can be done alternatively, which is considered adequate by are combined.
- ❖ This also can be done alternatively, which is considered adequate by taking $|I|+|Q|$. The combined unipolar output may be further processed for optimization of the signal. Further processing of these signals may be such as video correlator, video integrator.

❖ Example of MTI radar Processor

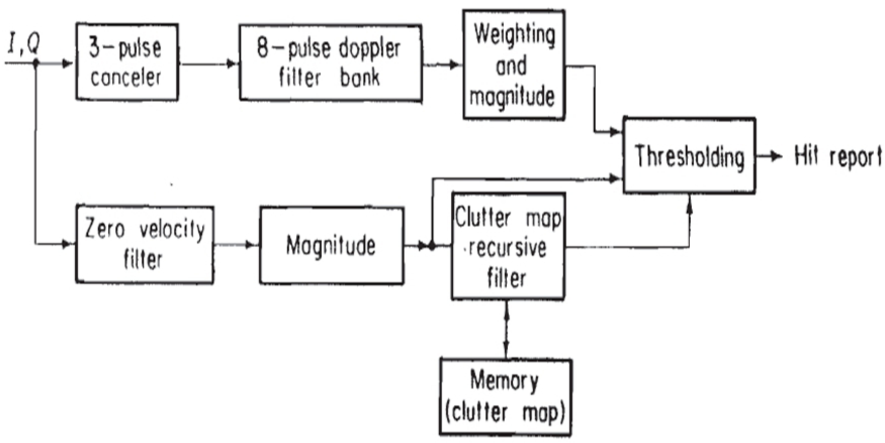


Figure 25.1. Block diagram of MTI radar processor

- The Moving Target Detector (MTD) is an MTI radar processor originally developed by the MIT Lincoln Laboratory for the FAA's Airport Surveillance Radars (ASR).
- The MTD processor employs several techniques for the increased detection of moving targets in clutter.
- Its implementation is based on the application of digital technology.
- It utilizes a three-pulse canceller followed by an 8-pulse FFT Doppler filter-bank with weighting in the frequency domain to reduce the filter side lobes, alternate PRFs to eliminate blind speeds, adaptive thresholds, and a clutter map that is used in detecting crossing targets with zero radial velocity.
- The measured MTI improvement factor of the **MTD on as ASR radar was about 45dB.**
- The three-pulse canceller and the eight-pulse Doppler filter-bank eliminate zero velocity clutter.
- The use of a three-pulse canceller ahead of the filter bank eliminates stationary clutter and thereby reduces the dynamic range required of the Doppler filter-bank.
- The fast Fourier transform algorithm is used to implement by the Doppler filter-bank.
- Since the first two pulses of a three-pulse canceller are meaningless only the last eight of the ten pulses output from the canceller are passed to the filter-bank.
- Weighting is applied in the frequency domain to reduce the filter side lobes.
- The output of the MTD is a hit report which contains the azimuth, range, and amplitude of the target return as well as the filter number and PRF.
- The MTD processor eliminates a large amount of the clutter and has a low false detection rate, its output can be reliably remote via narrow bandwidth telephone circuits.

Non coherent MTI (EXTERNALLY COHERENT)

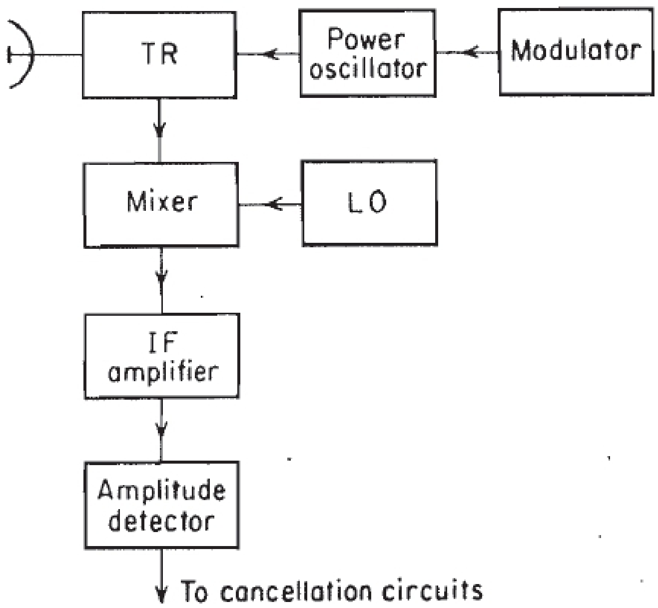


Figure 25.2. Block diagram of Non coherent MTI

- The echo signal received from a moving target or from clutter fluctuates both in amplitude and phase. Where the MTI makes the use of phase fluctuation than it is called coherent MTI and where the amplitude fluctuation is being than it is called as noncoherent MTI. In non-coherent MTI, the amplitude fluctuation is used to recognize the Doppler components produced by a moving target. It is also called externally coherent.

- The block diagram of non-coherent MTI is shown in fig. 25.2. In non-coherent MTI amplitude limiter cannot be used otherwise desired amplitude fluctuation would be lost. Instead of using phase detector we are using amplitude detector. Therefore, IF amplifier should be linear and should have large dynamic range.
- A logarithm amplifier may be used as IF amplifier to have logarithm gain characteristics, such as protection from saturation and have uniform output with variations in the clutter input amplitude. The output of IF amplifier to be detected over the A- scope.
- A butterfly effect can be observed on the A-scope due to the Doppler in amplitude fluctuation. The transmitter should be stable over the pulse duration to prevent beat from the overlapping ground clutter.
- **Advantages:**
    1. It is very simple and may be used where space and weight are limited.
- **Limitation:**
    1. The target must be in the presence of relatively large clutter signals if moving-target detection is to take place.
    2. Clutter echoes may not always be present over the range at which detection is desired.
    3. The clutter serves the same function as does the reference signal in the coherent MTI. If clutter were not present, the desired targets would not be detected.
    4. It is possible, however, to provide a switch to disconnect the non-coherent MTI operation and revert to normal radar.

Pulse Doppler Radar

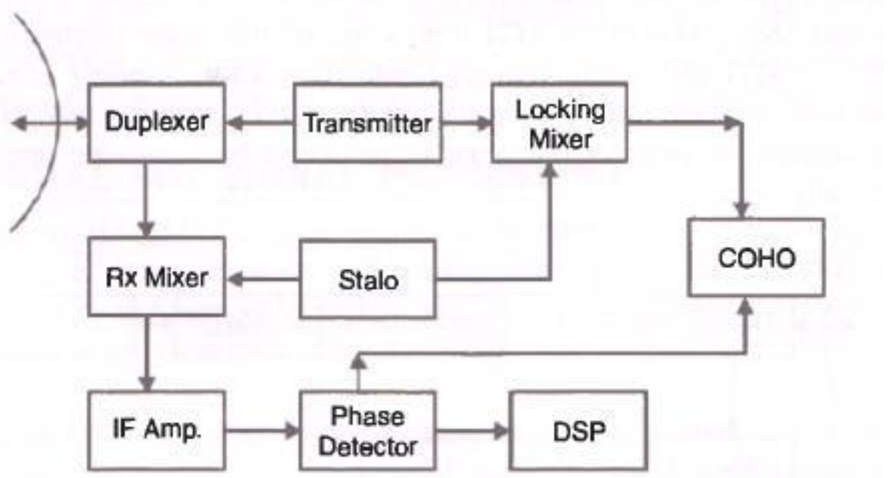


Figure 25.3. Block diagram of pulse Doppler radar

- Pulse radar is a combination of pulse radar and CW radar. It works on the principal of Doppler shift as MTI radar follows. As per the Nyquist Criterion the sampling rate (i.e. PRF) should be greater and equal to the twice of the Doppler shift frequency but in MTI due to use of low frequency it's became under sampled.
- It will leads to ambiguous estimation of target speed and occurrence of blind speed, where target appears stationary and unresolvable against the back ground clutter. Pulse Doppler radar being high PRF radar, it can remove the Doppler ambiguities.
- To extract the Doppler shift information of the carrier the pulse radar should be modified by introducing a coherent oscillator (COHO) for frequency stability in the transmitter and receiver chain. It employs the coherent radar system.

- Pulse Doppler radar is classified as high PRF and as medium PRF. In high PRF pulse radar there is ambiguity in the range but unambiguity in the velocity. In the medium PRF pulse radar there is ambiguities in range and velocity both.
- A STALO (stable local oscillator) is used to allow the phase of transmitter signal to be maintained by a locking mixer. The output of locking mixer given to lock the COHO phase and in turn it serves as reference phase for the detector at intermediate frequency.
- Now, the phase detector measures the difference in phase between two RF signal. Due to the target motion the phase path of the echo changes pulse path of the echo changes pulse to pulse and by the same amount phase difference will vary.
- **Applications:**
    1. It is being used as weather warning radar at the airbases to detect and measure thunderstorm, turbulence in the air.
    2. It is very useful in detecting and estimating the target motion, locking of particular target out of the group.
    3. To observe thunderstorm, rain and hail, a double polarization Doppler radar is being used.
- **Advantages:**
    1. A pulse Doppler radar has got the ability to reject the unwanted echoes by using Doppler filters or by a range gating.
    2. It can measure the range and velocity over predetermined limits, even in presence of multiples target.
    3. Signal to noise ratio can be increased by using coherent integration

MTI from moving platform

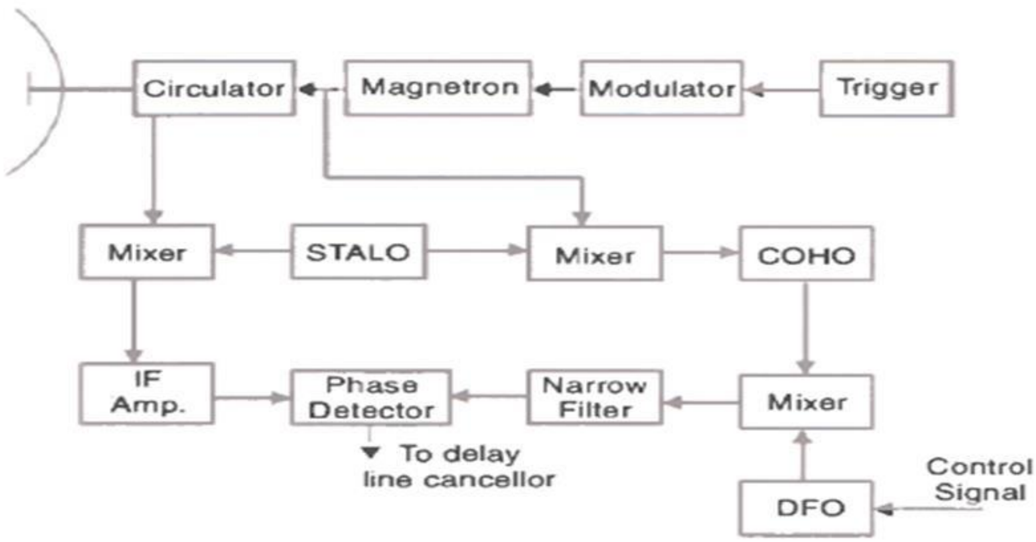


Figure 26.1. Block diagram of MTI from moving platform

- When radar is mounted on ship or on aircraft and it is in motion the detection of moving target in presence of clutter becomes more difficult than when it is stationary.
- In AMTI Doppler shift of the clutter varies with the direction of antenna in azimuth and elevation angle to the clutter.
- Clutter velocity depends on aircraft velocity and the direction of the clutter relative to the aircraft velocity vector.
- Doppler frequency is given by,

$$f_d = 2\,(v/\lambda)\cos\Theta$$
$$\Delta f_d = 2\,(v/\lambda)\sin\Theta\,\Delta\Theta$$

- Where,
  v = Platform speed
  Θ = Azimuth angle
- If the beam width is taken as $\Delta\Theta$ then Δf_d represents the measure of the width of Doppler freq. spectrum.
- Effect of AMTI considered as having two component:
  1) Direction of antenna pointing
  2) Normal to the direction of antenna.
- The frequency of COHO is shifted to compensate for the relative velocity of the radar platform with respect to the clutter.
- DFO (Doppler freq. oscillator) is being used which is a tuned oscillator.
- The o/p of this oscillator is made to be proportional to the relative velocity b/w radar and clutter and may be controlled according to the position of the antenna with respect to clutter.
- **Pulse Doppler MTI:-**
- A pulse Doppler MTI radar can be a better from of AMTI radar. In this using a rejecter filter can eliminate the ground clutter signal, which are being shifted in frequency by the Doppler Effect.
- If the rejection cannot continuously track the changing doppler frequency caused by a relative velocity, a narrow pencil beam may be used in which change in doppler occur as antenna is scanned in angle.
- **Non-coherent MTI radar:-**
- Due to less weight and space occupied by a non-coherent MTI, it is being preferred in aircraft, the non-coherent AMTI is limited, as its ground based counterpart, by the need for sufficient clutter signal to provide the reference upon which the Doppler fluctuation may be detected.
- **Fluctuation caused by platform motion:-**
- The clutter that the radar illuminates consists of number of independent scatters randomly.
- The each echo signals add vectorically at the receiving antenna.
- A change in distance so change in phase and vector addition of the all the echo signals may not be same pulse to pulse.

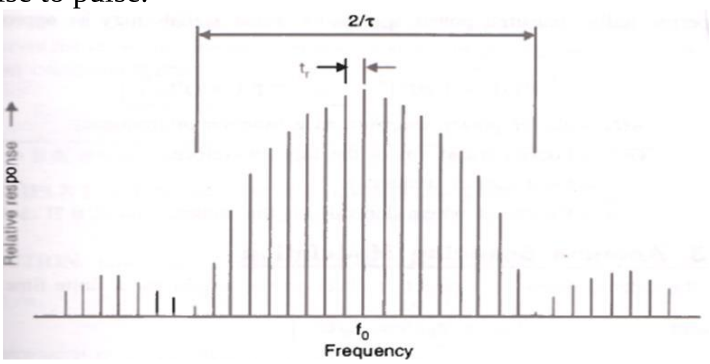


Figure 26.2. Spectrum of pulse radar transmitted waveform

- Although the side lobes radiator may be small compare to main beam but it will contribute large clutter from the ground.
- If there is no movements in target and radar and no clutter echoes, the freq. spectrum of the echo signal would be same them as that of transmitted signal.
- However the relative motion b/w radar & target as well as b/w radar & clutter and additional clutter signal received from the antenna side lobes will modify this signal spectrum.

CHAPTER 6 Tracking and Imaging Radar

- **Tracking with Radar**
- A tracking-radar system
  1. Measures the coordinates of a target and
  2. Provides data which may be used to determine the target path and to predict its future position.
- All or only part of the available radar data-range, elevation angle, azimuth angle, and Doppler frequency shift may be used in predicting future position; that is, a radar might track in range, in angle, in Doppler, or with any combination.
- Almost any radar can be considered a tracking radar provided its output information is processed properly. But, in general, it is the method by which angle tracking is accomplished that distinguishes what is normal normally considered a tracking radar from any other radar.
- It is also necessary to distinguish between a continuous tracking radar and a track while-scan (TWS) radar.
- The continuous tracking radar supplies continuous tracking data on a particular target, while the track-while-scan supplies sampled data on one or more targets. In general, the continuous tracking radar and the TWS radar employ different types of equipment.
- The antenna beam in the continuous tracking radar is positioned in angle by a servomechanism actuated by an error signal.
- The various methods for generating the error signal may be classified as sequential lobbing, conical scan, and simultaneous lobbing or mono pulse.
- The range and Doppler frequency shift can also be continuously tracked, if desired, by a servo control loop actuated by an error signal generated in the radar receiver.
- **Conical scan**

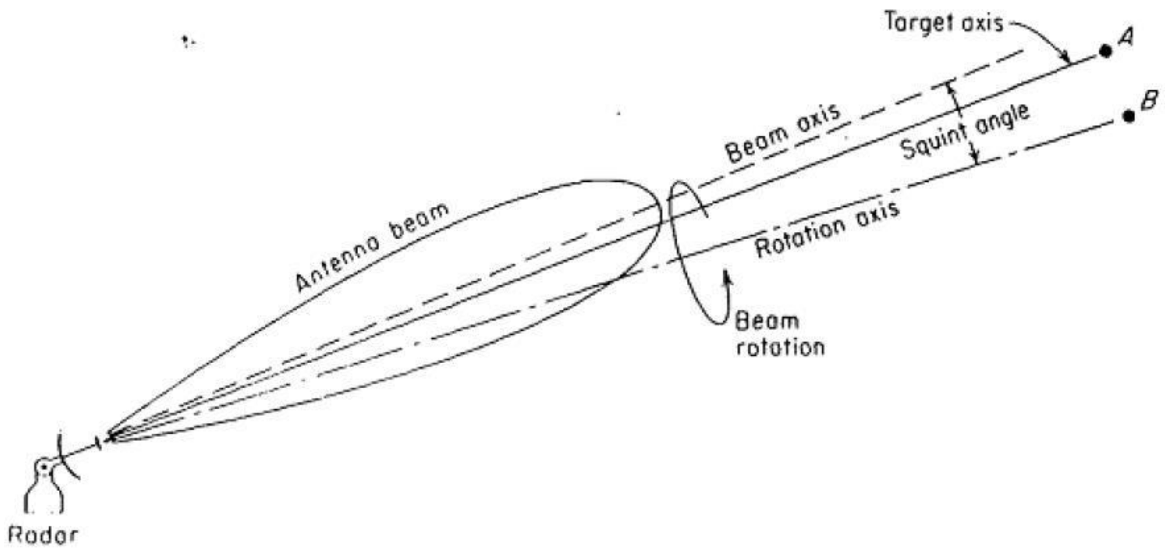


Figure 27.1. Conical scan track

- The logical extension of the sequential lobbing technique is to rotate continuously an offset antenna beam rather than discontinuously step the beam between four discrete positions. This is known as conical scanning (Fig. 27.1). The angle between the axis of rotation (which is usually, but not always, the axis of the antenna reflector) and the axis of the antenna beam is **called the squint angle.**

❖ Consider a target at position A. The echo signal will be modulated at a frequency equal to the rotation frequency of the beam. The amplitude of the echo-signal modulation will depend upon the shape of the antenna pattern, the squint angle and the angle between the target line of sight and the rotation axis.

❖ The phase of the modulation depends on the angle between the target and the rotation axis. The conical scan modulation is extracted from the echo signal and applied to a servo-control system which continually positions the antenna on the target. When the antenna is on target, as in B of Fig. 27.1, the line of sight to the target and the rotation axis coincide, and the conical-scan modulation is zero.

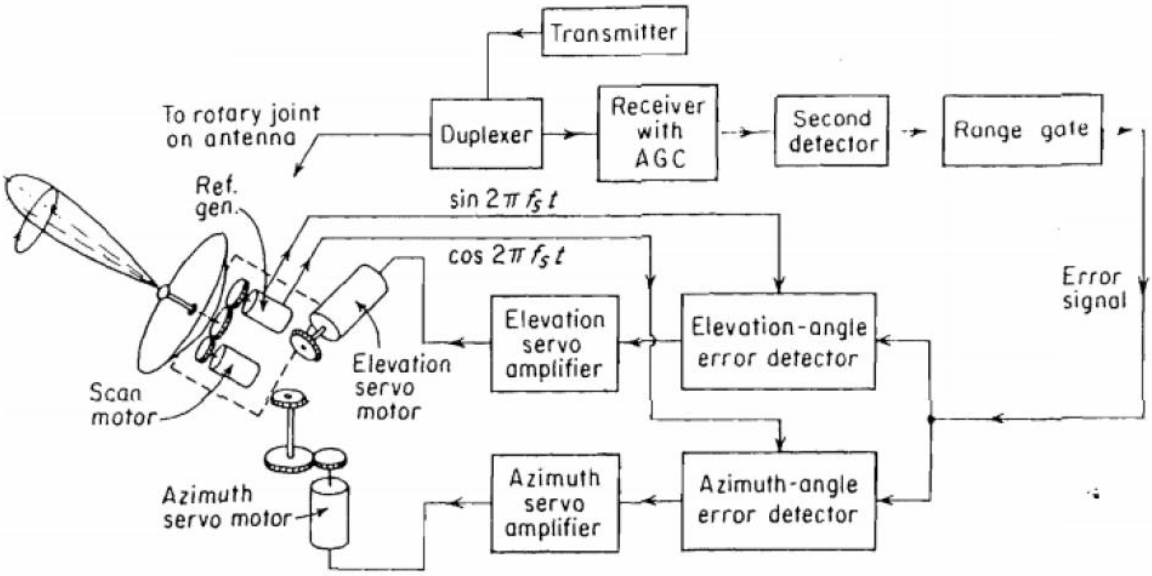


Figure 27.2. Block diagram of conical scan

❖ A block diagram of the angle-tracking portion of a typical conical-scan tracking radar is shown in Fig. 27.2. The antenna is mounted so that it can be positioned in both azimuth and elevation by separate motors, which might be either electric- or hydraulic driven. The antenna beam is offset by tilting either the feed or the reflector with respect to one another.

❖ One of the simplest conical-scan antennas is a parabola with an offset rear feed rotated about the axis of the reflector. If the feed maintains the plane of polarization fixed as it rotates, it is called a nutating feed.

❖ A rotating feed causes the polarization to rotate. The latter type of feed requires a rotary joint. The nutating feed requires a flexible joint. If the antenna is small, it may be easier to rotate the dish, which is offset, rather than the feed, thus avoiding the problem of a rotary or flexible RF joint in the feed.

❖ A typical conical-scan rotation speed might be 30 r/s. The same motor that provides the conical-scan rotation of the antenna beam also drives a two phase reference generator with two outputs 90° apart in phase. These two outputs serve as a reference to extract the elevation and azimuth errors.

❖ The received echo signal is fed to the receiver from the antenna via two rotary joints (not shown in the block diagram). One rotary joint permits motion in azimuth, the other, in elevation.

❖ The receiver is a conventional super heterodyne except for features peculiar to the conical scan tracking radar. One feature not found in other radar receivers is a means of extracting the conical-scan modulation, or error signal. This is accomplished after the second detector in the video portion of the receiver.

- The error signal is compared with the elevation and azimuth reference signals in the angle-error detectors, which are phase-sensitive detectors. A phase sensitive detector is a nonlinear device in which the input signal (in this case the angle-error signal) is mixed with the reference signal.
- The input and reference signals are of the same frequency. The output d-c voltage reverses polarity as the phase of the input signal changes through 180°. The magnitude of the d-c output from the angle-error detector is proportional to the error, and the sign (polarity) is an indication of the direction of the error. The angle-error detector outputs are amplified and drive the antenna elevation and azimuth servo motors.
- The angular position of the target may be determined from the elevation and azimuth the antenna axis. The position can be read out by means of standard angle transducers such as synchronous, potentiometers, or analog-to-digital-data converters.
- **Advantages:-**
  1. It require a minimum no. of hardware so inexpensive.
  2. It is used in mobile system AAA or a mobile SAM sites.
- **Disadvantages:-**
  1. It is not able to see target outside their narrow scan patterns.

Sequential Lobbing

- A simple pencil-beam antenna is not suitable for tracking radars unless means are provided for determining the magnitude and direction of the target's angular position with respect to some reference direction, usually the axis of the antenna.
- The difference between the target position and the reference direction is the **angular error.**
- When the angular error is zero, the target is located along the reference direction.
- One method of obtaining the direction and the magnitude of the angular error in one coordinate is by alternately switching the antenna beam between two positions is called **lobe switching, sequential switching, or sequential lobbing.**

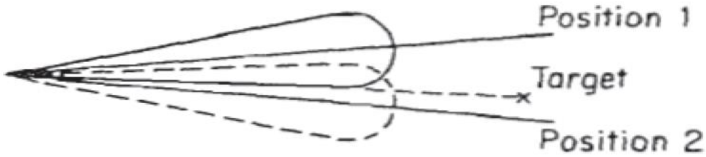


Figure 27.3. Dual beam polar pattern in sequential lobbing

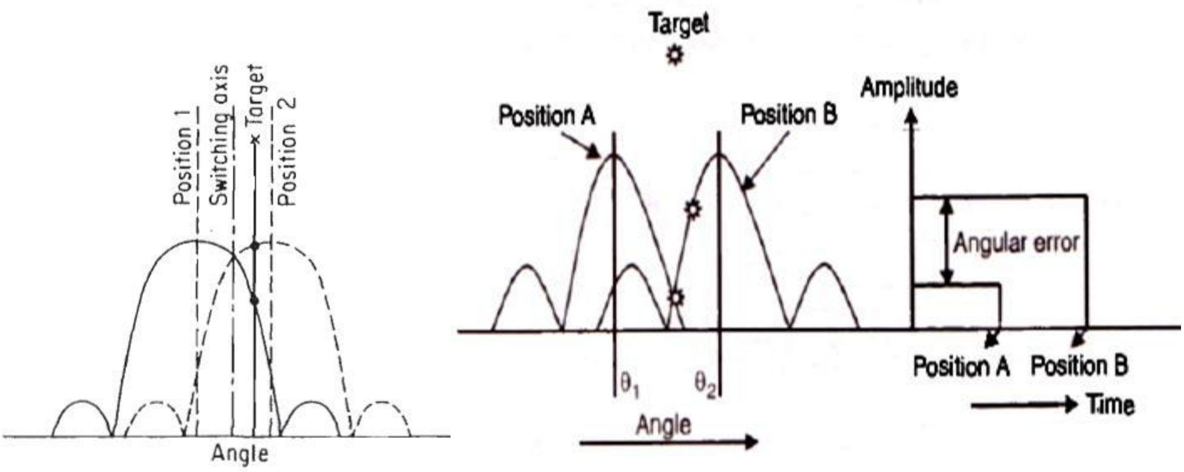


Figure 27.4. Rectangular representation and error signal

- There are total four switching position (up-down, right-left) are needed (two additional) to obtain angular error in orthogonal coordinate.
- **Advantage:-**
    1. Target position accuracy can be better than the size of antenna beam width.

- ## Mono-pulse Tracking
- There are two disadvantages in conical scanning and sequential lobbing.
    1. The motion of the antenna is more complex in both.
    2. In conical scan a min. of four pulse is required. Due to the effect of target cross section and the effect of fluctuating echo sometimes need of no. of pulses to extracting error.
- This prob. Can be overcome by using only one pulse.
- The tracking technique which derive angle error information on the basis of single pulse is known as a mono pulse tracking or simultaneous lobbing more than one antenna beam is used simultaneously where as in conical scanning and sequential lobbing one antenna beam is used on the time shared base.
- **Amplitude comparison Mono-Pulse**
- In this four feeds are used with one parabolic reflector.
- There are four horn antennas are used.
- The receiver received three types of signal
    1. Sum signal (A+B+C+D)
    2. Azimuth error signal=(A+C)-(B+D)
    3. Elevation error signal=(A+B)-(C+D)

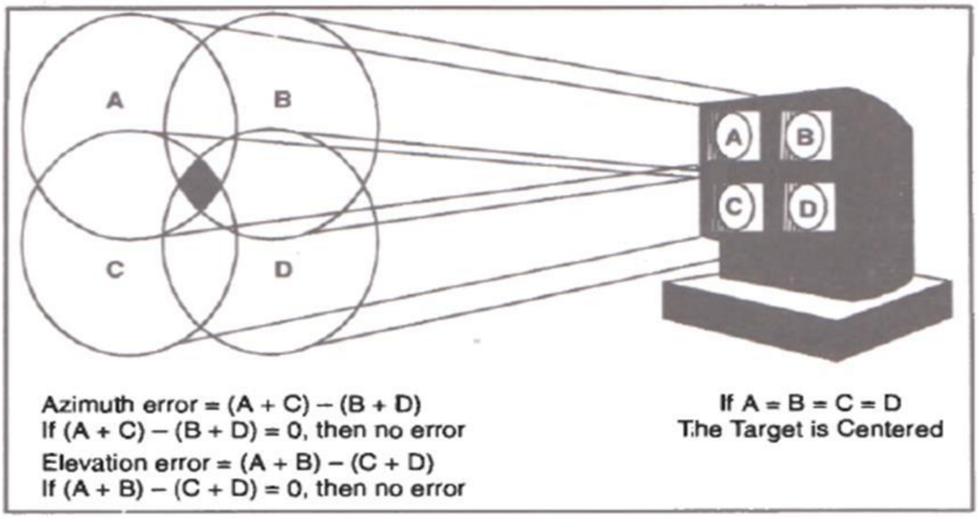


Figure. 28.1. Mono-Pulse radar beam pattern

- In this technique it is important that the signal arriving at various feeds are in phase.
- In case of array where the antenna surface is very large signals arriving from different off -axis angles present different phases.
- So their phases need to be equalized before error signal are developed.
- Sum signal is used for transmission and difference signals are used in reception.
- The receiver has three separate input channel consisting of three mixers, common local oscillator, three IF amplifiers and three detector.
- The elevation and azimuth error signals are used to drive a servo amplifier and a motor in order to position the antenna in the direction of target.

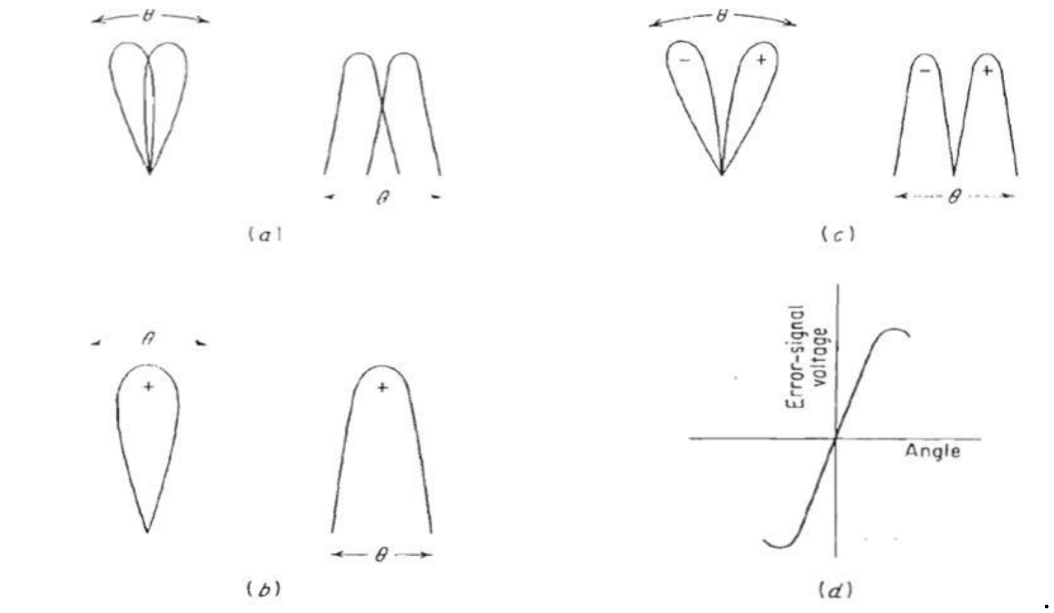


Figure 28.2. (a) Overlapping pattern (b) Sum pattern (c) Difference pattern (d) Error signal

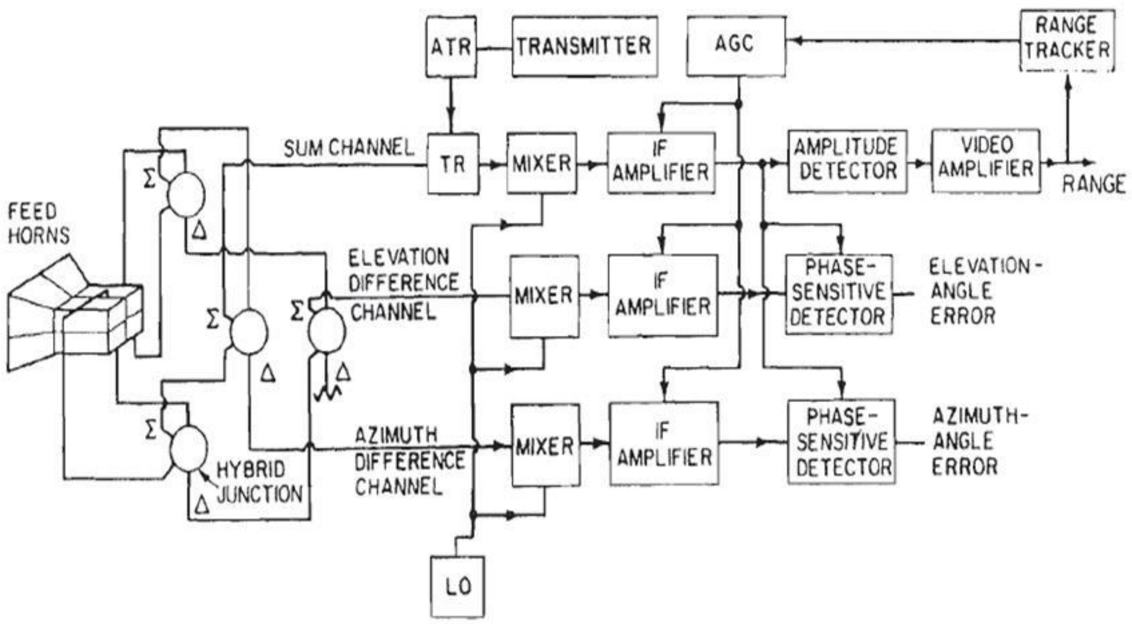


Figure 28.3. Block diagram of amplitude comparison mono-pulse tracking radar

- The o/p of sum channel is used to provide the data generally obtain from a radar receiver so that it can be used to provide the data generally obtain from a radar receiver. So that it can be used for application like automatic control of the firing weapon.
- **Advantages:-**
  1. Only one pulse is require to obtain all the information regarding the target and able to locate target in less time comparing other methods.
  2. In this generally error is not occur due to the variation in target cross section.
- **Disadvantage:-**
  1. Two extra Rx channel is required and more complex duplexer feeding arrangement, which makes system bulky and more complex and also expensive.
- **Application:-**
  1. Automatic control of the firing weapon.

❖ **Phase comparison Mono-pulse tracking**

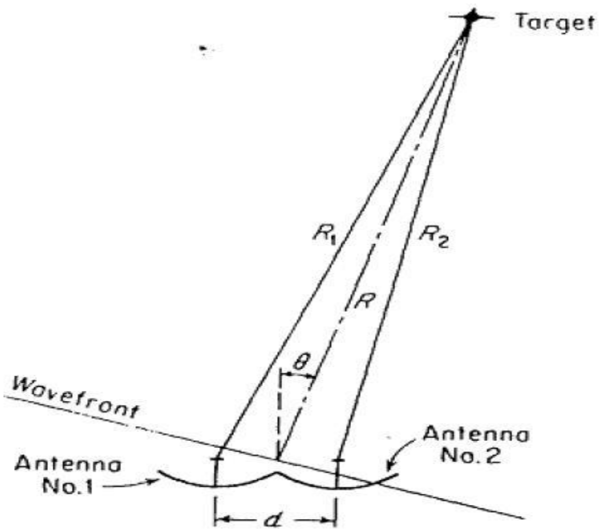


Figure 28.4. Wave front phase relationship for phase comparison monopulse radar

❖ The measurement of angle of arrival by comparison of the phase relationships in the signals from the separated antennas of a radio interferometer has been widely used by the radio astronomers for precise measurements of the positions of radio stars.
❖ The interferometer as used by the radio astronomer is a passive instrument, the source of energy being radiated by the target itself. A tracking radar which operates with phase information is similar to an active interferometer and might be called an interferometer radar. It has also been called Simultaneous phase comparison radar, or phase comparison monopulse.
❖ In Fig. 4 two antennas are shown separated by a distance d. The distance to the target is R and is assumed large compared with the antenna separation d. The line of sight to the target makes an angle θ to the perpendicular bisector of the line joining the two antennas. The distance from antenna 1 to the target is

$$\mathbf{R_1 = R + (d \sin \theta) / 2}$$

❖ And the distance from antenna 2 to the target is

$$\mathbf{R_2 = R - (d \sin \theta)/ 2}$$

❖ The phase difference between the echo signals in the two antennas is approximately

$$\mathbf{\Delta\varphi = 2\pi\, d \sin\theta / \lambda}$$

❖ For small angles where sin θ = 0, the phase difference is a linear function of the angular error and may be used to position the antenna via a servo-control loop.
❖ In the early versions of the phase-comparison monopulse radar, the angular error was determined by measuring the phase difference between the outputs of receivers connected to each antenna.
❖ The output from one of the antennas was used for transmission and for providing the range information. With such an arrangement it was difficult to obtain the desired aperture illuminations and to maintain a stable bore sight.
❖ A more satisfactory method of operation is to form the sum and difference patterns in the RF and to process the signals as in a conventional amplitude-comparison monopulse radar.
❖ **Disadvantages:-**

1. The side lobes levels, which result higher than the signal antenna.
2. The phase comparisons radar does not usually make efficiently use of the total available antenna aperture.

❖ Low Angle Tracking

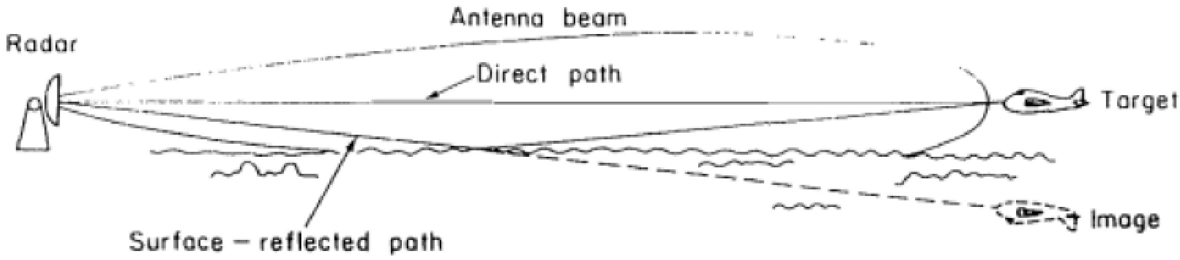


Figure 29.1. Low angle tracking

- ❖ A radar that tracks a target at a low elevation angle, near the surface of the earth, can receive two echo signals from the target, Fig. 29.1. One signal is reflected directly from the target, and the other arrives via the earth's surface.
- ❖ The direct and the surface-reflected signals combine at the radar to yield angle measurement that differs from the true measurement that would have been made with a single target in the absence of surface reflections.
- ❖ The result is an error in the measurement of elevation. The surface-reflected signal may be thought of as originating from the image of the target mirrored by the earth's surface. Thus, the effect on tracking is similar to the two-target model used to describe glint. The surface-reflected signal is sometimes called a multipath signal.
- ❖ The surface-reflected signal travels a longer path than the direct signal so that it may be possible in some cases to separate the two in time (range). Tracking on the direct signal avoids the angle errors introduced by the multipath. The range-resolution required to separate the direct from the ground-reflected signal is;

$$\Delta R = 2h_a h_t / R$$

- ❖ Where,

  h_a = radar antenna height,
  h_t = target height,
  R = range to the target.
- ❖ For a radar height of 30 m, a target height of 100 m and a range of 10 km, the range resolution must be 0.6 m, corresponding to a pulse width of 4 ns. This is a much shorter pulse than is commonly employed in radar. Although the required range-resolutions for a ground based radar are achievable in principle, it is usually not applicable in practice.
- ❖ The use of frequency diversity can also reduce the multipath tracking error.

❖ Synthetic aperture radar (SAR)

- ❖ A synthetic aperture radar (SAR) achieves high resolution in cross range dimension by taking advantages of the motion of the vehicle Carrying the radar synthesized the effect of the large antenna aperture.
- ❖ Synthetic aperture radar is a form of radar in which sophisticated post-processing of radar data is used to produce a very narrow effective beam. It can only be used by moving instruments over relatively immobile target, but it has seen wide application in remote sensing and mapping.
- ❖ The imaging of the earth surface by SAR to provide a map like display can be applied to military reconnaissance, measurement of sea state and ocean wave condition, geological and mineral explorations.
- ❖ **Basic operation**

- In a typical SAR application, a single radar antenna will be attached to the side of an aircraft. A single pulse form the antenna will be rather broad because diffraction require a large antenna to produce a narrow beam.
- The pulse will also be broad in the vertical direction; often it will illuminate the terrain from directly beneath the aircraft out if the horizon.
- However if the terrain is approximately flat the time at which echoes return allows point at different distance from the flight track to be distinguished.
- Distinguishing point along track of the aircraft is difficult with a small antenna.
- However if the amplitude and phase of the signal returning from a given piece of ground are recorded and if the aircraft emits a series of observation can be combined just as if they had all been made simultaneously from a very large antenna: this process creates synthetic aperture much larger than the length of the antenna.
- Combining the series observation is done using FFT. The result is map of radar reflectivity on the ground. The phase information is in the simplest application, discarded. The amplitude information contains information about ground cover.

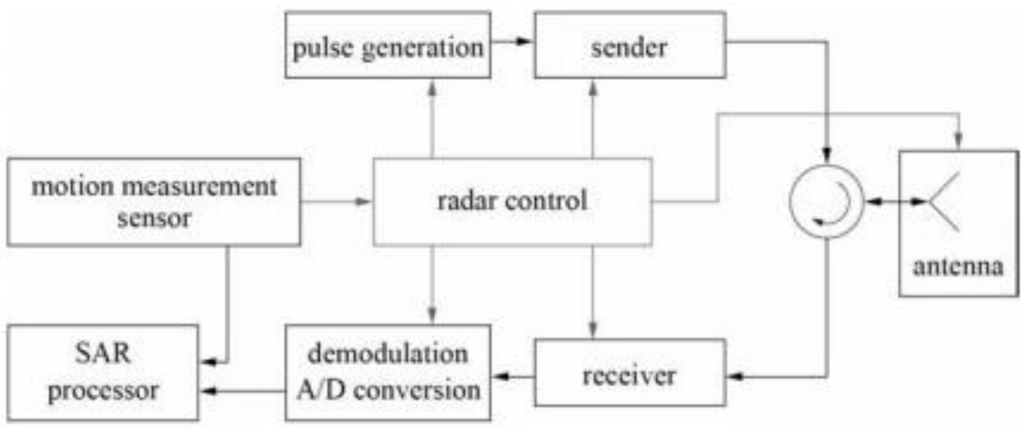


Figure 29.2. General structure of SAR

- Main parts of a SAR system are depicted in Figure 29.2. A pulse generation unit creates pulses with a bandwidth according to the aspired range resolution. They will be amplified by the sender and are transferred to the antenna via a circulator.
- The receiver gets the antenna output signal (echoes of the scene) amplifies them to an appropriate level and applies a band pass filter. After the demodulation and A/D conversion of the signals the SAR processor starts to calculate the SAR image.
- Additional motion information will be provided by a motion measurement system. A radar control unit arranges the operation sequence, particularly the time schedule.

CHAPTER 7 NAVIGATION AIDS

- **Introduction**
- **Navigation:** The art of directing the movements of a craft (object) from one point to another along a desired path is called navigation.
- In short navigation is process to finding a short & secure path to travel.
- **Aids of navigation :**
    - Compass
    - Chronometer
    - Sextant
    - The Sun, The Moon, The Stars & The Winds
    - The Theodolite & Charts (Maps of known world)
- **The Compass:**
- A compass is a navigational instrument that shows directions in a frame of reference that is stationary relative to the surface of the Earth.
- The frame of reference defines the four cardinal directions (or points) – north, south, east, and west.
- Intermediate directions are also defined. Usually, a diagram called a compass rose, which shows the directions (with their names usually abbreviated to initials), is marked on the compass.
- When the compass is in use, the rose is aligned with the real directions in the frame of reference, so, for example, the "N" mark on the rose really points to the north.
- The magnetic compass was first invented as a device for divination as early as the Chinese Han Dynasty (since about 206 BC).
- A simple compass is shown in figure 1.

Figure 1

- **The Chronometer:**
- A chronometer is a clock that is precise and accurate enough to be used as a portable time standard; it can therefore be used to determine longitude by means of celestial navigation.
- When first developed in the 18th century, it was a major technical achievement, as accurate knowledge of the time over a long sea voyage is necessary for navigation, lacking electronic or communications aids.
- The first true chronometer was the life work of one man, John Harrison, spanning 31 years of persistent experimentation and testing that revolutionized naval (and later aerial) navigation and enabling the Age of Discovery and Colonialism to accelerate.

❖ Figure 2 shows the Chronometer.

Figure 2

❖ **The Sextant:**
❖ A sextant is an instrument used to measure the angle between any two visible objects.
❖ Its primary use is to determine the angle between a celestial object and the horizon which is known as the object's altitude.
❖ Using this measurement is known as sighting the object, shooting the object, or taking a sight and it is an essential part of celestial navigation.
❖ The angle, and the time when it was measured, can be used to calculate a position line on a nautical or aeronautical chart.
❖ Figure 3 shows the Sextant.

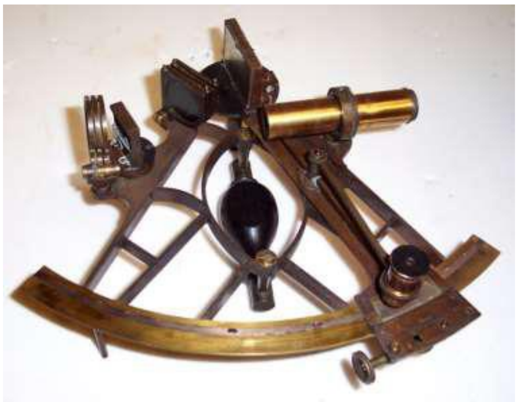


Figure 3

❖ **The Theodolite:**
❖ A theodolite is a precision instrument for measuring angles in the horizontal and vertical planes.
❖ Theodolites are used mainly for surveying applications, and have been adapted for specialized purposes in fields like metrology and rocket launch technology.
❖ A modern theodolite consists of a movable telescope mounted within two perpendicular axes—the horizontal or trunnion axis, and the vertical axis.
❖ When the telescope is pointed at a target object, the angle of each of these axes can be measured with great precision, typically to seconds of arc.
❖ Figure 4 shows the Theodolite.

Figure 4

- Magellan circumnavigated the Globe in the early sixteenth century with the aid of listed instruments.
- In eighteenth century the Chronometer, a very accurate clock, was produced.
- With the chronometer the navigator was able to determine his longitude by noting the transit time.
- Navigation became science as well as art.
- In twentieth century, electronics entered the field.
- Time signals were broadcast by which the Chronometers could be corrected.
- Direction finders and other navigational aids which enable the navigator to obtain a fix using entirely electronic aids were developed and came into extensive use.
- Our aim is to study about all navigational aids which employ electronics in some way.
- To start with a brief account of other methods of navigation.

Four Methods of Navigation

- Navigation requires the determination of the position of the craft & the direction in which it has to go to reach desired destination
- The currently used methods of navigation may be divided into four classes :
  - Navigation by Pilotage (or Visual Contact)
  - Celestial or Astronomical Navigation
  - Navigation by dead-reckoning
  - Radio Navigation
- **Navigation by Pilotage (or Visual Contact):**
- In this method, the navigator fixes his position on a map by observing known visible landmarks.
- For e.g., in air navigation when the ground is visible the navigator can see the principal features on the ground such as rivers, coastlines, hills etc. and thereby fix his position.
- Even at night, light beacons, cities and towns provide information about position of the craft.
- Pilotage navigation requires good visibility.
- With aid of air-borne radar it is called as Electronic-Pilotage.
- The radar used for this purpose is microwave search radar provided with PPI display on which the terrain is mapped.
- The PPI picture has poor resolution compared to human eye because the angular resolution is typically 3°.

- Electronic-Pilotage has the range of 50 to 100kms that is advantageous in poor visibility.
- Can't applicable over sea.
- Both methods of Pilotage depend upon the availability of accurate maps of the terrain.
- **Celestial or Astronomical Navigation:**
- Also called as astronomical navigation is accomplished by measuring the angular position of celestial bodies.
- Almanacs giving the position of celestial bodies at various times measured in terms of GMT.
- The navigator measures the elevation of celestial body with a sextant and notes the precise time at which the measurement is made with a chronometer. These two measurements are enough to fix the position of the craft on a circle on the face of the globe.
- If two such observations are made, the position or fix of the craft can be identified as one of the two points of intersections of the circles.
- Sometimes the 3rd observation may have to be made to remove the ambiguity.
- Figure 1 illustrates the celestial navigation.

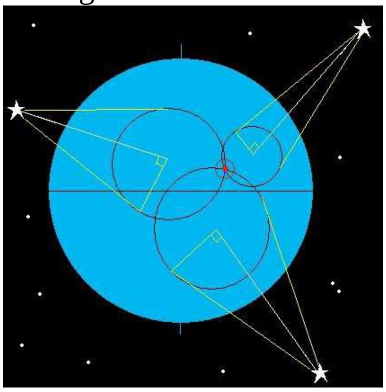


Figure 1

- Its advantage is relative independence of external aids.
- Its disadvantage is that the visibility should be good enough to take elevation angles of bodies.
- This may not be always possible at sea, but in air navigation, with modern aircraft flying at altitudes above 5000 m. visibility is always good.
- The accuracy is totally dependent on measured elevation of the body and generally correct to 1 min. of arc.
- **Navigation by dead-reckoning:**
- In this method, the position of craft at any instant of time is calculated from the previously determined position, the speed of its motion w.r.t. Earth along with the direction of its motion and the time elapsed.
- Abbreviated as DR stands for "Deduced Calculation".
- This is the most common and widely used method of navigation.
- This method requires the direction of motion of the craft and speed of motion.
- First requirement may be met by magnetic compass & second by an instrument such as air speed indicator in aircraft and the mechanical log in ships.
- DR Navigation would be straight forward if the medium in which the craft travels is stationary.
- In air navigation, wind velocity is generally obtained in the course of flight from weather broadcasts or by communication with ground station.
- In long flights over water, modern air operations resort to minimal flight paths i.e. the paths which require min. flying time.

- **Radio Navigation:**
- This method is based on Electromagnetic waves to find the position of the craft.
- All these systems depend upon transmitters & receivers at known locations on earth's surface & transmitters & receivers working in conjunction with them in the vehicle.
- These systems are not self-contained systems of navigation like the DR system because it is dependent on the installation of instruments on the craft as well as on the earth.
- These systems generally give the navigational parameters like distance, direction & time by measuring the delay directly or indirectly in reception.
- The positional information is related to the
    - The measurement of direction
    - The measurement of distance
    - The difference in distance of two transmitters
- These give locus of the craft on a
    - Line
    - Circle
    - Hyperbola

Radio Direction-finding:

- The earliest method of electronic navigation was by direction finding i.e. the determination of the direction of arrival of EM waves at the receiving station.
- EM waves travel along great circle path so it helps to locate the transmitter along the great circle path.
- Oldest method but still use in both ships & aircraft.
- Transmitter & direction finder may be located on ground or on the craft & vice-versa.
- If direction finder located at ground then it obtain the bearing & passes on the information to the craft by a radio communication channel.
- Direction-finding may be carried out in any region of the radio spectrum but certain frequencies are specifically allotted for navigational purpose in the LF/MF, HF & VHF bands.

Loop Antenna & its emf equation:

- Consider a rectangular loop antenna as shown in figure 1 of length *a* & width *b* with its plane vertical, mounted so that it can be rotated about the vertical axis.

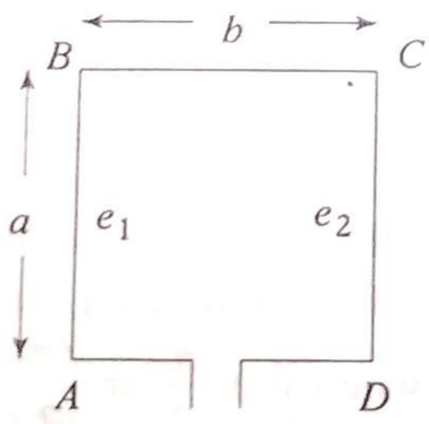


Figure 1 Loop Antenna

- Let vertically polarized electromagnetic wave incident on it making an angle θ with the plane of the loop as shown in figure 2.

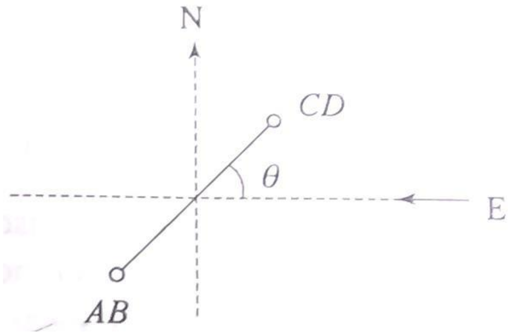


Figure-2 EM wave arriving with the angle θ

- Voltages are induced in the vertical members of the loop but not in horizontal members as the wave is vertically polarized.
- Magnitude of the voltage induced in two vertical members is $a\varepsilon$.
- The voltages in the two members will not be in phase can be seen from phasor diagram as shown in figure 3.

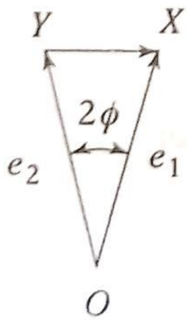


Figure-3 Phasor diagram

- The voltage induced in AB is lags by an angle Φ.

$$\phi = \frac{2\pi}{\lambda}\frac{1}{2}B\ \cos\theta = \frac{\pi}{\lambda}B\ \cos\theta$$

- If the electric field at the centre of the loop is $\varepsilon\ (t) = \sqrt{2}\ \varepsilon\ \cos(\omega t)$
- Voltages induced in AB & CD are

$$e_1 = \sqrt{2}a\varepsilon\ \cos\left(\omega t - \frac{\pi}{\lambda}b\cos\theta\right)$$

$$e_2 = \sqrt{2}a\varepsilon\ \cos\left(\omega t + \frac{\pi}{\lambda}b\cos\theta\right)$$

- So the resultant output is e_L& it is given by,

$$e_L = e_1 - e_2 = \sqrt{2}\varepsilon\frac{2\pi}{\lambda}ab\cos\theta\sin\omega t$$

- From equation (2) the output amplitude is proportional to cos θ.
- The polar diagram of the loop antenna is, therefore a 'figure of eight' as shown in figure 4.

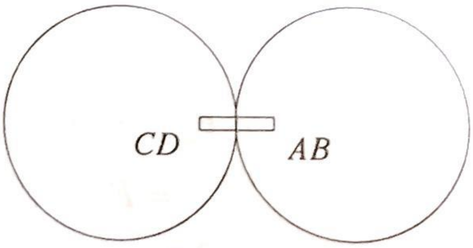


Figure-4 Polar diagram

Loop input circuits:

- The loop antenna is by itself inductive and the loop output is not generally used directly as an input to the receiver.
- A variety of circuits is used at the input of direction finding receivers to obtain a voltage which is larger than the loop voltage and to establish the desired phase relation between the loop out of the loop circuit and the output of the vertical antenna for sense finding.
- Some of these circuits discussed here, as shown in figure 1 the inductance of loop is tuned out by a capacitor and making a series tuned circuit and the voltage across capacitor or half of it is used as input of the receiver.

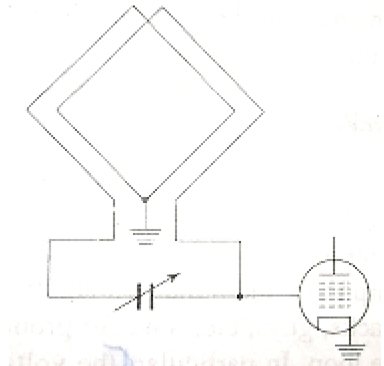


Figure-1 Series tuned circuit

- The series tuned circuit provide the certain amount of circuit magnification of the loop voltage.
- As the current in a series tuned circuit is in phase with applied voltage the voltage across the capacitance lags by 90° with respect to the input voltage.
- Figure 2 & 3 shows developments of the same circuit to achieve a batter balance than is possible with the first circuit.

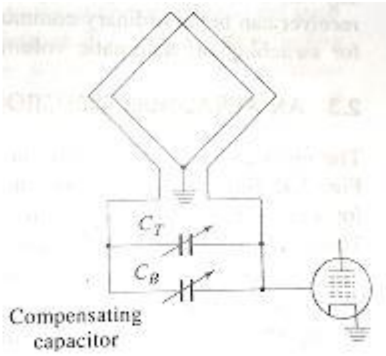


Figure-2 Balanced circuit

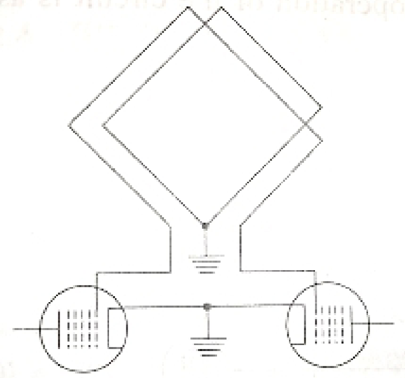


Figure-3 Balanced circuit

- One of the important sources of antenna effect is the asymmetry of the loop antenna with respect to the ground.
- To minimize antenna effect the centre of the loop is earthed and its output is, thereby balanced.
- If the input stage of the receiver is single ended half the voltage across the tuning capacitor is applied to the grid of the first stage and some unbalance may be introduced by the input capacitance.
- To remove such unbalance either a compensating capacitor as shown in figure 2.
- In all adjustments aimed at eliminating antenna effect, a check is made to see whether the minima correspond to opposite bearing by tuning in a station and turning the loop.
- Ideally two bearing obtained must differ by 180° and any departure from this figure is minimized by adjustment of the compensating circuits.
- Balancing of the loop is made more effective and accurate by enclosing it in an electrostatic shield which is broken at one point near the top as shown in figure 4.

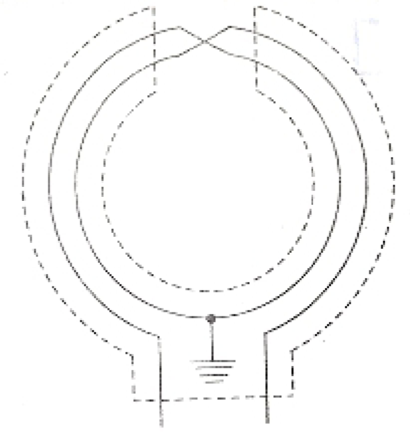


Figure-4 Screened loop

- A completely shielded loop will not pick up any signal but if a break is introduced the performance of the loop is affected while any unbalance introduced by surrounding objects is minimized.
- The receiver can be an ordinary communications receiver but with the arrangement for switching off automatic volume control.

An aural null direction finder:

- The input circuit of a manually operated loop direction-finder is shown in figure 5.
- This circuit illustrate one method by which the voltage required for sense finding may be obtained an introduced in to the loop circuit.
- There is provision in this circuit for sharpening the nulls.
- On shipboard, the presence of metallic objects such as stacks, guys etc. tends to produce, by re-radiation, undesirable voltages in the loop.
- The loop circuit consisting of the loop antenna, L_1, C_1 and L_2 is a series tuned circuit for the loop voltage.
- In the ‘balance’ position of the switch S, an additional voltage is introduced through the variable inductive coupling between L_3 & L_1.
- This voltage is obtained from the vertical antenna & the components C_2, L_5 & C_3 are so adjusted that this voltage is in phase quadrature to the loop voltage.
- With the variation in magnitude & sign permitted by the variable coupling between L_1 & L_3, the quadrature component arising from antenna effect can be cancelled out.
- For sense finding, the switch S is thrown to position 2.
- The vertical antenna circuit has now a large series resistance R_1.

- The current in L_4 is in phase with the vertical antenna voltage & the voltage induced in L_2 is in phase quadrature to this, i.e. it is either in phase or in phase opposition to the loop voltage.
- This satisfies the requirement for sense finding.
- The magnitude of this voltage can be adjusted to the optimum value to get good sense discrimination by adjusting the resistance R_1.
- The direction finding procedure consists of following steps
    - With the switch S in position balance, the bilateral bearing of the signal source is found.
    - The loop is then turn by 90° & the switch is thrown to the 'sense' position. Then by noting whether the signal strength increases or decreases the sense can be determined.
- Proper mechanical arrangement is provided for both measurements i.e. sense & direction.

Goniometer:

- The loop direction-finder has the disadvantage that the loop has to be small enough to be rotated easily.
- This results in relatively small signal pickups further, to facilitate manual operation, the loop has to be located near the receiver.
- This is a requirement which is not always easy to meet, particularly on ship-board.
- Both these disadvantages are eliminated by using two fixed loops, mutually perpendicular, and combining their outputs in a 'goniometer'.
- The loops, being fixed, can be as large as practicable and the goniometer can be placed along with the receiver in any convenient location.
- The antenna and goniometer arrangement is shown in figure 1.

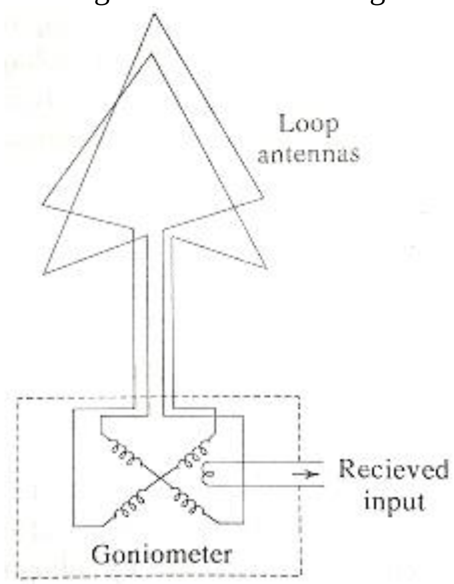


Figure-1 Sketch of the goniometer

- The goniometer consists of two windings, mutually perpendicular (called the 'stators'), and a winding at the centre of these, called the 'rotor', which can be rotated about the axis of symmetry.
- The two fixed loops are connected to the two stator windings and the voltage induced in the rotor is taken to the receiver.
- It will be shown in the following paragraph that the voltage induced in the rotor is equivalent to the voltage in a rotating loop antenna.

- Referring to figure 2, let the two loops be oriented N-S and E-W and let the incident electromagnetic wave (vertically polarized) make an angle θ with the North.

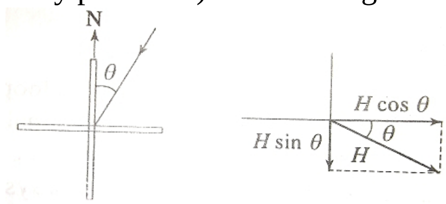


Figure-2 Plan of the Loop antennas& The magnetic field within the goniometer

- The currents flowing in the two loops are then proportional to cos θ (N-S Loop) and (cos 90 - θ) = sin θ (E-W loop).
- For convenience, let the corresponding stator coil be called N-S coil E-W coil.
- The magnetic flux in these coils produced by the loop currents are proportional to cos θ and sin θ respectively (figure-2) and the resultant magnetic flux has the same direction with respect to N-S loop.
- The voltage induced in the rotor is maximum when the flux is perpendicular to the plane of the rotor and zero when it is parallel to the plane of the rotor.
- The bearing can be found by turning the rotor to a null, and taking the direction of the rotor to the normal to the N-S stator coil as the direction of the incoming wave with respect to North.
- The signal from the rotor can be combined with the signal from the vertical antenna for sense finding.

Errors in Direction Finding:

- The analysis of loop direction finder vertically polarized wave is arriving at the antenna from the direction of the transmitter.
- This condition will hold good only for ground wave propagation over a perfectly conducting earth.
- In practice this is not possible so the wave may not be normally polarized, it may be incident at an angle at the antenna and the direction of its arrival may not be the same as that of the transmitter.
- Errors will arise in direction-finder due to this condition.
- These may be divided into four broad classes as given below,
    - Errors due to abnormal polarization
    - Errors due to abnormal propagation
    - Site errors
    - Instrumental errors

Polarization Errors:

- This type of errors was mainly observed at night time,
- Which was characterized by displace minima, rapid changes in their position, a poor null, etc.
- The cause of this proved to be the abnormal polarization associated with inospheric propagation.
- As sky waves were more prominent at night in low frequency band.
- This phenomenon is known as ‘night effect’.
- Abnormal polarization also occurs in radiation from aircraft transmitters and hence called as ‘aero plane effect’.

Errors due to abnormal propagation:

- It was earlier assumed that the EM Waves travelled along the great circle path from transmitter to the direction-finder.
- This is generally true but some time the path deviates from the great circle plane.
- When the propagation is via the ionosphere, such deviation can occur owing to scattered reflections and tilt of the reflecting regions.
- As both these phenomena are associated with propagation via ionosphere, they are more evident at high frequency.
- Abnormal propagation can also occur at low and medium frequencies under certain condition.
- When the direction-finder is near a coast and the direction of arrival of the wave makes a small angle with the coast line, there is a bending of the wave towards the land owing to the differences in the conductivity of the sea and land.
- The transmitter appears to be more towards the sea than it actually is.
- This phenomenon is sometimes called ‘coastal reflection’.
- These errors are generally small and generally constant and could be corrected by calibration.
- A similar phenomenon may be observed in mountain terrain this is called as “mountain effect’’.

Site Errors:

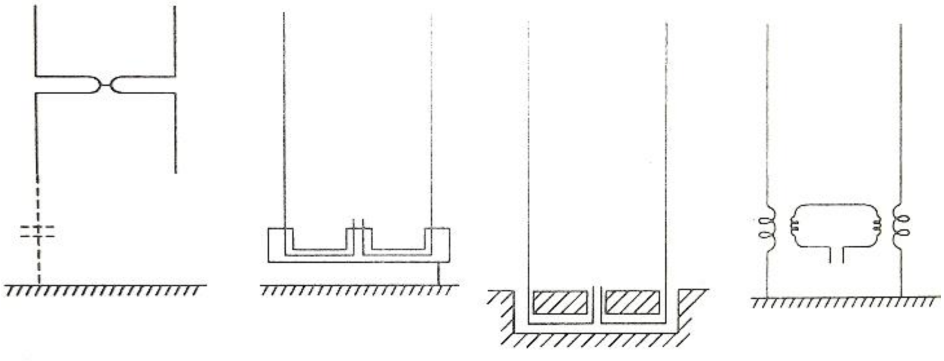
- An ideal site for a direction-finder must be flat and must have high conductivity.
- In practice these conditions are not full filled and errors arise either on account of reflections from large surfaces or on account of re-radiation from various objects nearby.
- Even objects underground, such as berried cables , spikes ,etc. can produce errors because the soil conductivity is low and EM waves penetrates the soil to some depth.
- If the direction-finder is placed near the large objects that introduces site errors.
- In a mobile installations such as on a ship-board the choice of site is vary restricted and the direction-finder is invariably surrounded by objects which absorbs the some of the energy from the wave and re-radiate it.
- Site errors can be minimized to some extant but not eliminated completely.

Instrumental Errors:

- Imperfections of the components used in direction-finders generates the errors, these errors are instrumental errors can be compensated by calibration.

Adcock Direction Finder:

- It was shown in the last lecture that polarization errors arise owing to the voltage picked up by the horizontal members of the loop.
- The Adcock antenna is designed to eliminate polarization error by dispensing with the horizontal members.
- It consists of pair or more of vertical antennas, the signals from these being taken to the receiver either by underground conductor or by shielded balanced pair of wires.
- In the first case, no voltage will be induced in the horizontal member, if the conductivity of the earth is good, and in the second case, whatever voltage are induced in the two horizontal members tend to cancel out.
- Several forms of the Adcock antenna are shown in figure 1.



(a) 2° – 6° (b) 6° – 10° (c) < 5° (d) 1°

Figure-1 Adcock direction finders (the standard wave error is indicated in each case)

- These are generally called U-type or H-type Adcock antennas, depending on the position of the horizontal members, relative to the vertical members.
- Electrically the Adcock antenna is equivalent to a single turn loop and therefore for equal size the output of Adcock antenna is higher compare to loop antenna.
- To compensate for this, the vertical antennas are made large and consequently, a fixed antenna system in conjunction with a goniometer is employed at the low, medium and high frequencies.
- The need for large antennas also makes the Adcock direction –finder unsuitable for mobile installations.
- Another disadvantage of this antenna is that it has a high internal impedance which is largely capacitive and presents some difficulties in connecting it to the input circuits of a receiver.
- Sense-finding in the Adcock antenna system is carried out in the same manner as in the loop systems by using a vertical antenna.
- The Adcock direction-finder is not completely free from polarization errors, because some voltage is induced in the horizontal members even when buried underground.
- The errors are, however, reduced. Typical values are also indicated in figure 1.
- In antennas of the type shown in figure 1(a) which are used commonly in the VHF band, errors can arise due to unequal capacitance between the antenna and the earth, but they become less as the height of the antenna system above the earth is increased.

Advantages over loop antenna:

- The loop antenna direction finder suffers from vertical & polarization errors but in Adcock direction finder system these errors are minimized.
- The loop direction finders are suitable at lower frequency, whereas Adcock direction finder is suitable for higher frequency.
- The induced voltage in Adcock system is less in comparison to loop

Direction finding at very high frequency:

- Direction-finding in the frequency band 100-150 MHz is widely employed for aeronautical navigation purposes.
- This is done by ground-based installations, which obtain the aircraft bearing and pass it to the aircraft by radio telephony.
- Adcock direction –finders are invariably used for this purpose.
- In the VHF band, the size of the vertical antenna and its spacing are such that the complete antenna system can be easily rotated.

- ❖ A typical manually operated installation consists of a rotatable aerial system mounted on a mast above the direction-finder (DF) but the receiver in the hut.
- ❖ Modern direction-finders are commonly of automatic type and used a crossed-H Adcock antenna with a capacitor goniometer.
- ❖ The principles of operation a “phase - comparison” direction-finders are described in previous lecture. An alternative type is employing modulation techniques.
- ❖ Recently, a direction –finding employing a new technique has been developed.
- ❖ This is commutated Aerial Direction-Finder (CADF).
- ❖ As VHF propagation is confined essentially to line odd sight ranges, direction – finders in this band mainly serve aircraft, though some use is made of them for harbour control.
- ❖ Errors at these frequencies generally originate from polarization and site irregularities.
- ❖ Radiation from aircraft is often abnormally polarized and in spite of using vertical HAdcock antennas, some error will be present, particularly when the radiation is incident from a high angle.
- ❖ Site errors are more prominent when the radiation arrives at a low angle and in this case, the choice of a good site is important.

Automatic Direction finders:

- ❖ Manually operated direction finders are simple in construction, but needs an operator always, in aircrafts this is not possible.
- ❖ Also it has the disadvantage of speed of operation at very high speed it cause errors in direction finding.
- ❖ So the automatic direction finders are introduced here we have two types
  1) The Radio Compass
  2) A VHF Phase-comparison
- ❖ **<u>The Radio Compass:</u>**
- ❖ The radio compass uses a loop antenna in a servo feed-back system.

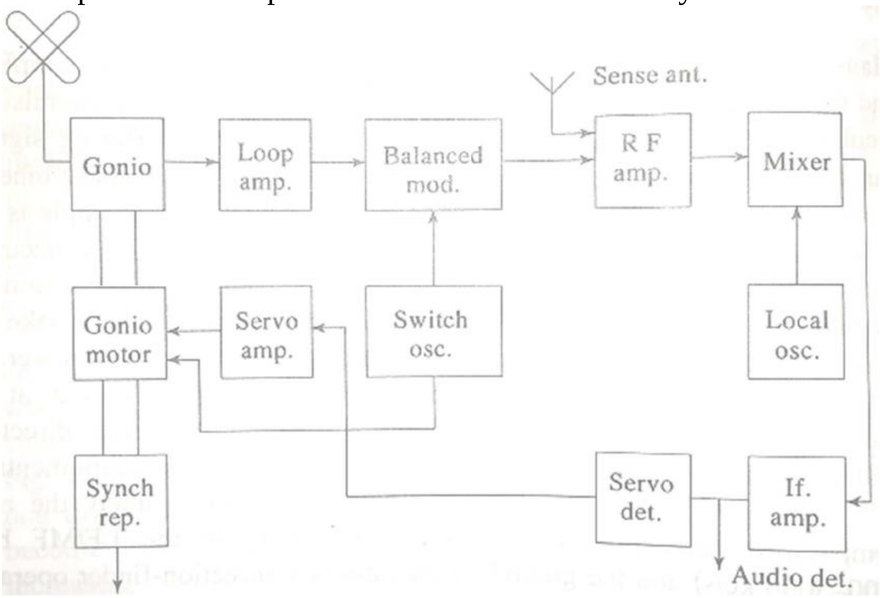


Figure-1 Block diagram of a radio compass receiver

- ❖ The equipment provided with a pair of loop and a gonio which is mechanically coupled to a motor & a synchro-generator.
- ❖ The motor is a two phase one, actuated by two input one from switch oscillator & other one from servo amplifier.

- The direction of the torque on the motor correspondingly changes its sign depending on the position of the loop and the motor tends to move the gonio to the position of the zero torque or the null.
- To obtain an output which is dependent on the phase of the gonio signal, the following method is employed.
- The output of the gonio is fed to a balanced modulator & modulated by a signal from the switching oscillator.
- The output of the balanced modulator, which consists only of the side band components, is combined with the sense aerial input, which is phase shifted so as to be in phase with the suppressed carrier of the signal.
- The resultant is fed to a super-heterodyne amplitude modulated receiver.
- The demodulated output of this will have a switching frequency waveform, the phase of which, in relation to the input to the balanced modulator, will now be determined.
- **<u>A VHF Phase-comparison Automatic Direction-Finder:</u>**
- The principle of operation of this DF can be understood if one examines the nature of the output obtained from an Adcock aerial to which the output of a vertical aerial situated in the centre is added.
- As an Adcock pair is equivalent to a loop aerial, the output may be same as loop antenna.

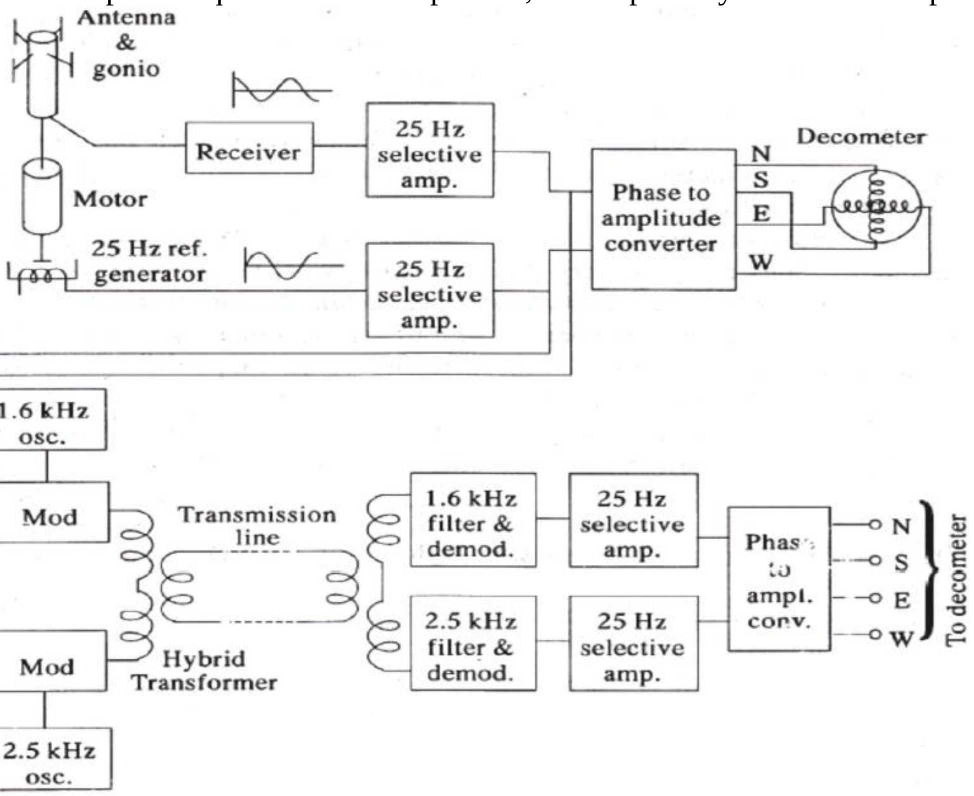


Figure-2 Block diagram of VHF automatic direction-finder (Marconi ADF)

- The DF employs a pair of fixed Adcock antennas with a capacitance goniometer to obtain the rotating figure-of-eight pattern. Instead of using a vertical antenna for obtaining a fixed phase signal, an unbalanced output is taken from the capacitance goniometer rotor.
- The vector sum of the voltages induced in the rotor, when combined with the figure of eight pattern gives the required cardioid.
- The goniorotor is coupled to a motor and rotated at 25 rps.
- To the same shaft is attached an ac generator which gives a 25Hz ac voltage of fixed reference phase.

- The signal from the goniometer, which is modulated at 25 Hz by the rotation of the rotor, is applied to the receiver and after demodulation and amplification is passed through a selective amplifier and is applied to a phase measuring device along with the signal from the reference generator.
- For remote indication, the two 25Hz signals are made to amplitude modulate two audio frequency carriers which-are then transmitted to the remote point where they are demodulated and the two modulating 25 Hz signals are recovered.
- These are then applied to a phase-meter.
- Which consists of two coils mounted on a spindle to indicate the direction.

Range and Accuracy of Direction Finders:

- Ground-based direction-finders are generally of the Adcock type and are relatively free from polarization errors.
- In day time, such installations when installed on a good site have the limiting accuracy of the instrumentation, generally of the goniometer, which may be under 1, if calibrated.
- At night time, when sky wave propagation is predominant, error will arise which may range from 2 to 4 depending on the distance of the transmitter (150 to 600 km).
- Most ground-based Adcock stations operate between 2 and 3 MHz and serve ships.
- Such stations are not suitable for aircraft as aircraft transmissions are generally confined to much higher frequencies because of the difficulties associated with equipping the aircraft with efficient antennas operating in this range.
- Ground-based VHF DFs are widely used, particularly in civil aviation.
- Their range is mainly limited by the line of sight propagation.
- The principal errors are due to the site.
- When such direction-finders are installed in an airport, these errors can be quite large.
- But with the provision of remote indication (as in ADF), the DF can be installed in a good site and the errors reduced.
- The commutated antenna DF enables a further reduction of site errors by a large factor.
- Airborne DFs are generally of the loop type and operate in the MF/LF band.
- Reliable operation is possible with ground waves up to several hundred miles under favourable conditions.
- Accuracies up to 2" (after correcting for aircraft quadrantal errors) are possible.
- At night times, sky waves contaminate the signal and long range operation is not possible.
- Under these conditions, fairly reliable operation is possible only at the lower end of the frequency range and up to much shorter distances (less than 150 km).
- The calibration of these DFs holds only at one frequency and the condition of pitch and roll may also alter it.
- Taking all these factors into consideration, the bearings obtained from ground wave cannot be relied on to better than +/- 5˚.
- In spite of the errors in the bearing determined, the aircraft (or ship) can always use the bearing for 'homing', i.e. going towards the transmitter.
- In the case of aircraft, when flying over the transmitter, a rapid reversal of bearing takes place.
- This gives an indication of the position of the aircraft.
- In the case of ships, it is inadvisable to home on to a beacon, because of the risk –of collision.
- Transmitters transmitting continuous waves or modulated continuous waves are widely used in civil aviation for navigational assistance.
- These are called 'non-directional beacons'.

Radio Range:

- Radio ranges are navigational aids which are mainly used by aircraft.
- There are two types of radio ranges in used, the low frequency four-course radio range and the VHF Omni-directional radio range.
- The former can be used by any aircraft equipped with a receiver which can be tune e to the frequency of the ground station, which is in the LF/MF range of 200-400 KHz, while the latter requires special equipment.
- The LF/MF radio range is obsolescent and so only a brief treatment of the principles of its operation is given.
- The VHF Omni-range (generally abbreviated or VOR) is in use in most parts of the world.

The LF/MF Four Course Radio Range:

- The LF/MF radio range employs two antenna systems each of which has a polar diagram of the figure-of-eight type, these two being at right angles to each other (figure 1(a)), the points of intersection of these two figures-of-eight when joined to the centre, give four directions in which the signals from the two sets of antennas have the same strength.

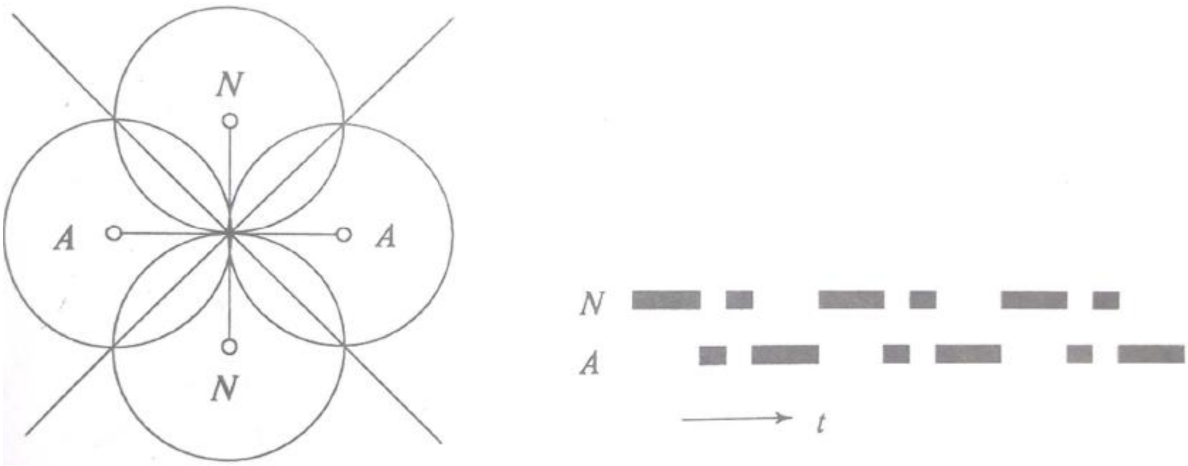


Figure-1 (a) polar diagram of the four-course radio range and (b) interlacing A and N transmissions

- These are called equi-signal courses.
- A transmitter is made to energize these antennas alternately by a relay called the link Circuit relay.
- In order to distinguish the transmission from the two antennas, one of them is made to transmit the letter N (— •) in Morse and the other to transmit the letter A(• —) th two being inter locked as shown figure 1(b).
- Both these transmissions are modulated by an audio frequency note of 1020Hz.
- When the aircraft is on course, the two signals being equal, a continuous note of 1020 Hz is heard.
- At point off the course, either the letter N or the letter A is predominant.
- Owing to the fact that the ear can distinguish only a finite change in the intensity of the signal, the equi-signal course appears spread over a small angle, generally about 3°.
- The radio range, thus provides four paths at right angles along which the aircraft can navigate.
- These paths are arranged to be along the most useful routes.
- In a variation of this system, called the SRA (Simultaneous Range Adcock) five antenna towers are used, four at the corners of a square and the fifth at the centre.

- Power is fed to all the antennas. The transmission the corner towers give rise to two figure-of-eight polar diagrams.
- The transmissions from the centre tower, which differs in frequency by 1020 Hz, combines with the others to give four equi-signal courses.
- In addition, by a combination of the power and phase of radio frequency energy fed to the four corner antennas, the figure-of-eight patterns can be reduced or increased in size and the two lobes of the pattern can be made unequal.
- This enables one to obtain courses which are not perpendicular to each other, as shown in figure 2.

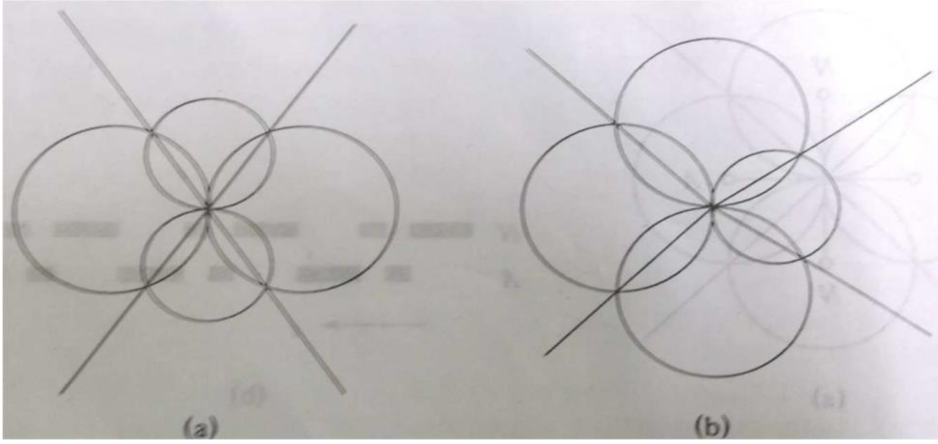


Figure-2 (a) Course shifting & (b) Course bending in LF/MF Radio range

- These are called course bending and course shifting.\
- In addition, by feeding the power to the antennas through a goniometer, rotation of the courses is also made possible.
- In this system it is possible to arrange the courses to serve routes which are not necessarily perpendicular to each other.
- **Disadvantages:**
    - Limited number of courses are available
    - Poor SNR
    - Continuous listening of sound may hurt operator's ear
    - Difficulty to identify the course

VHF Omni Directional Range:

- This facility operates in the range 108-136 Mhz in the VHF band.
- An aircraft provided with the appropriate receiving equipment can obtain its radial position with respect to the range by comparing the phases of two sinusoids obtained from the range radiation.
- Any fixed phase difference defines a radial course and so, in effect, the VOR may be regarded as providing an infinite number of courses, as against the four of the LF/MF radio range.
- **The principle of operation**
- The range transmitter radiates two patterns, distinguishable by different modulations, one of which is Omni-directional and caries the modulation of a reference 30 Hz sinusoid, while the second pattern is figure-of-eight one, and therefore, the combination gives rise to a rotating cardioid at the receiving point, the rotating cardioid, after demodulation, gives a 30 Hz signal of variable phase, while the Omnidirectional signal gives a 30 Hz signal of fixed reference phase.

- Figure 1 shows how the phase difference between these is equal to the bearing of the receiving point from the beacon transmitter.

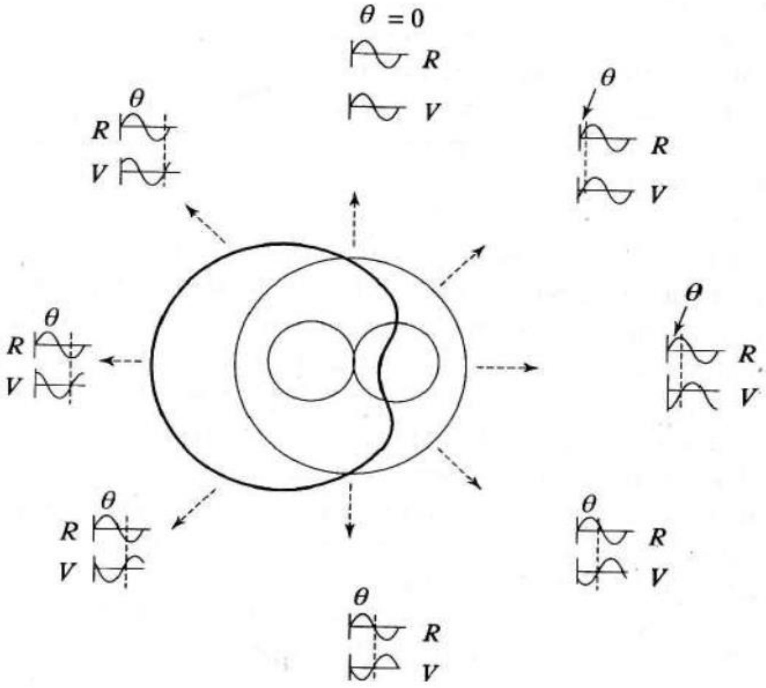


Figure-1 Reference (R) and variable-phase (V) signals of VOR received at various points

- By suitable instrumentation in the aircraft, this phase angle may be directly displayed on a meter.
- The dependence of the phase of the demodulated signal in the receiver on the bearing of the receiver is readily established in the following manner.
- Let the cardioid have its maximum in the direction of North at t = 0 and let it rotate clockwise with angular velocity ω_s.
- The equation of the cardioid (taken as representing the magnitude of the electric filed) in polar coordinates is:

  $\varepsilon = 1 + K \cos \theta$ (k<1)-----------------------(1)
- Where θ is the angle measured from North.
- This is shown by the full line cardioid in figure 2, where the maximum of the cardioid (θ = 0) is in the direction of the north.
- At a time *t*, when the cardioid has turned by angle $\omega_s t$, the filed magnitude in a direction ϕ is given by the same equation but with θ replaced by $\phi - \omega_s t$, as is clear from the cardioid shown by the broken line in figure 2.

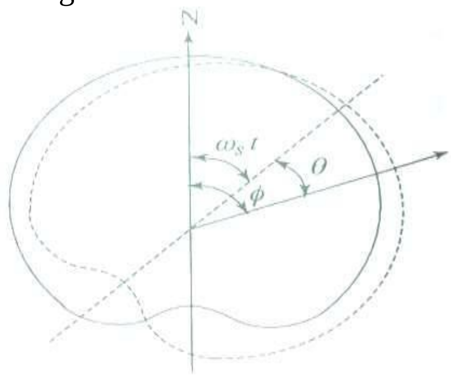


Figure-2 Production of variable phase signal by rotation of the cardioid pattern

- The signal received by a receiver in the direction 0 is therefore proportional to 1+k(cosϕ - ω_st), which has a sinusoidal component of angular frequency ω_s.
- By comparing the phase difference between this and a signal cosω_st, the angle ϕ, which is the desired bearing, can be determined.
- Note that the reference signal and the variable phase signal are in phase when the receiver is due north of the beacon.
- As the Omni-directional and figure-of-eight patterns have the same carrier frequency, the reference sinusoid cannot be made to directly amplitude modulates the former.
- To enable separation, the following method is employed.
- The radio frequency power fed to the Omni-directional antenna is amplitude modulated to a depth of 30% by a subcarrier with a mean frequency of 9960 Hz which its itself frequency modulated at 30 Hz, the maximum frequency deviation being 480 Hz.
- The variable phase signal is produced, as stated earlier, by the rotation of the phase locked figure-of-eight pattern.
- The magnitude of the signal received from the rotating pattern is such that it causes a 30% modulation of the Omni-direction carrier (i.e. k=0.3 in eq.3.1).
- The facility of modulating the Omni-directional pattern by voice is also provided.
- The various parts of the VOR equipment are shown in the block schematic figure 3.
- The figure pertains to the equipment developed by Federal telecom laboratories.

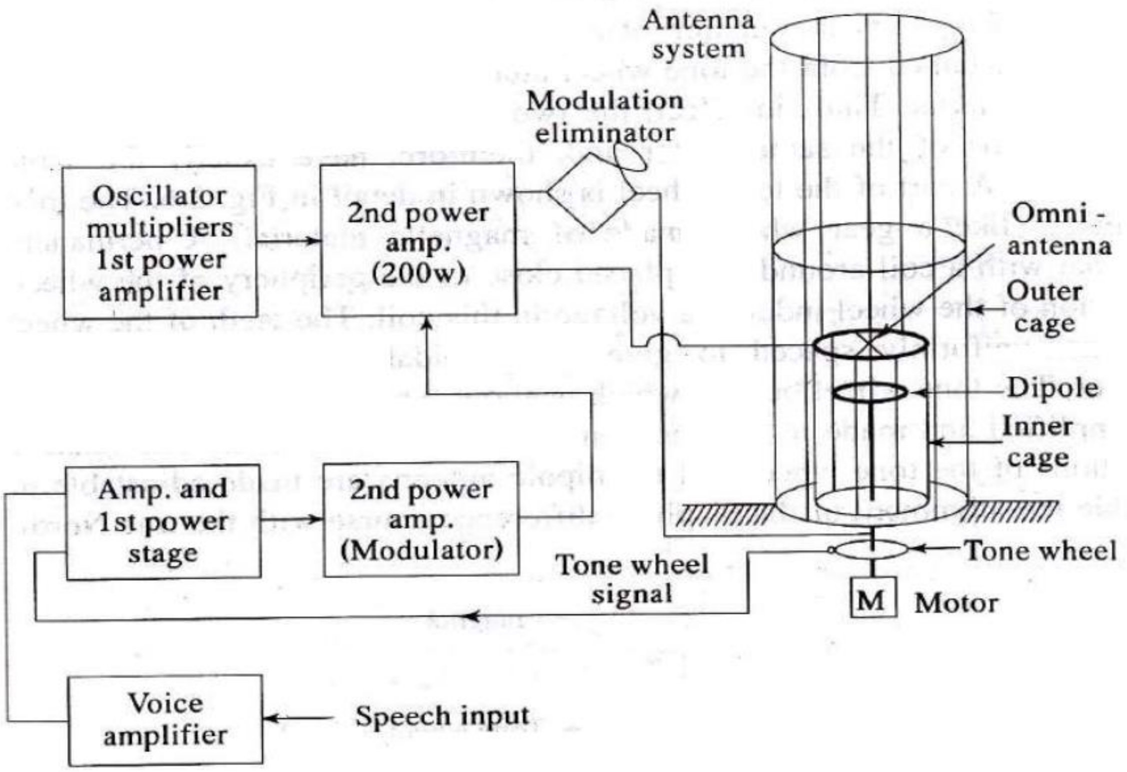


Figure-3 Block diagram of the VOR ground equipment

- This differs from the earlier equipment developed by the Civil Aeronautics Administration (CAA), mainly in respect of the antenna system and the way in which a rotating figure-of-eight is obtained.
- In the CAA equipment, four Alford loop antennas, energized through a capacitor goniometer were used.

- Rotation of the stator of the goniometer produced a rotation of the polar diagram. In the FTL equipment, this pattern is produced by a dipole antenna which is itself rotated. In both these equipment's the 9960 Hz sub-carrier which is frequency modulated at 30 Hz is obtained by a 'tone wheel' which is coupled to the rotating element nt. this part of the equipment will be descry bed latter.
- Figure 3 block diagram of the VOR ground equipment.
- Referring to figure 3, the transmitter consists of a crystal controlled oscillator, frequency multipliers and driver, and a power amplifier.
- The power amplifier is amplitude modulated by the modulator which is given an input consisting of the tone wheel signal (9960 Hz sub-carrier) and when desired, a voice signal.
- The output of the power amplifier is divided into two parts, the greater pa (about90%) of which goes directly to the Omni-directional antenna.
- The remaining part is passed through a modulation eliminator and energizes the rotating antenna. (In the CAA equipment, it goes to the rotor of the goniometer).
- The antenna system is a special cage-type one developed for this purpose.
- It consists of a disc-type antenna with four slots which gives the Omni-directional pattern and a rotating dipole which produces the figure-of-eight pattern.
- The latter is enclosed in a double-cage made up of vertical rods and two end-plates which act as a radial waveguide coupled to free-space through vertical slots.
- The dipole is only a tenth of a wave length long but because of its position within the waveguide.
- It presents resistive impedance. The outer of the two cages enclosing he antennas is extended up by 12 feet.
- The net result of the antenna structure is to give a radiation made up of the two required patterns, the polarization of the radiation being horizontal.
- This antenna is also simple to adjust for correct operation, as the difficulty of properly phasing the four Alford loops in older type of equipment is eliminated by the use of a rotating antenna.
- The 30 Hz reference phase signal, as stated earlier, is transmitted in the form of a frequency modulation of a 9960 Hz sub- carrier.
- This modulated carrier is obtained from the tone wheel attached to the motor which rotates the dipole aerial.
- Thus, in effect, the two 30 Hz signals are generated by the rotations of the same motor and therefore, have exactly the same frequency.
- A part of the tone wheel is shown in detail in figure 4.

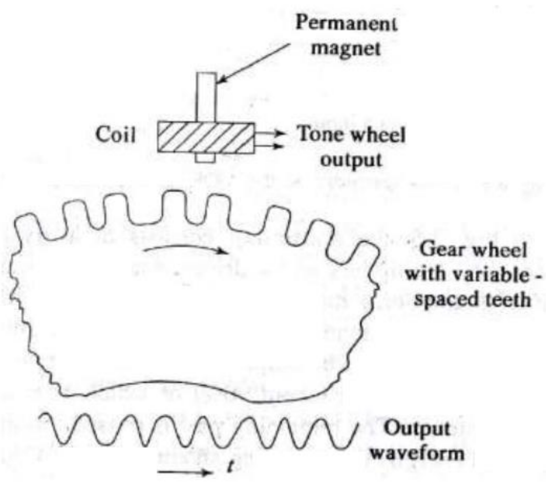


Figure-4 Detail of the Tone Wheel

- The tone wheel is like a gear wheel, made of magnetic material.
- A permanent magnet with a coil around it is placed closed to the periphery of the wheel.
- Rotation of the wheel induces a voltage in this coil.
- The teeth of the wheel are non-uniformly spaced to give a sinusoidal frequency modulated output.
- The tone wheel output, which is about 0.6 mW in a 600 ohm load, is amplified and made to amplitude modulate the transmitter.
- The relative positions of the tone wheel and the dipole antenna are made adjustable to enable the alignment of the 0 phase difference course with the true North.
- The importance of maintain the phase relation between the carrier of the Omnidirectional radiation and the figure-of-eight radiation has already been mentioned.
- This requirement is met by first modulating the carrier, then separating a part of it and removing its modulation.

VOR Receiving Equipment:

- The air-borne equipment which can utilize the VOR facility consists of a broad band Omni-directional antenna, a multichannel amplitude modulated receiver which can be tuned over the required band, and an instrumentation unit which processes the receiver output to obtain the course indication.
- In most of the modern installations, a common receiver is used for the reception of VOR and ILS signals and the demodulated output is switched to the required instrumentation and display circuits.
- The frequency band over which the receiver works in 108.0 to 135.95 MHz covering 560 allocations each separated from the adjacent ones by 50 kHz.
- Continuous tuning over this range is not desirable.
- Modern receivers are crystal controlled and tuned to spot frequencies.
- By a system of multiple heterodyning, the 560 channels are obtained with a limited number of crystals.
- Transistorized circuits are used in modern receivers.
- The essential elements of the instrumentation part of the receiver are shown in the block diagram of figure 1.

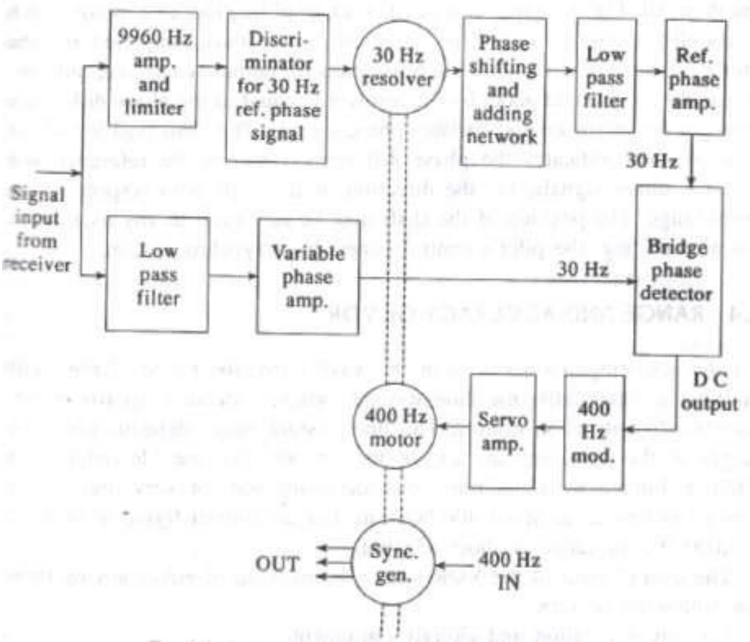


Figure-1 Instrumentation port of VOR receiver

- The demodulated output of the receiver, which is the input to the instrumentation unit contains the variable phase 30 Hz signal and the reference phase signal as frequency modulation on the 9960 Hz sub-carrier.
- These are separated by filters into two channels.
- The reference phase signal is passed through an amplitude limiter, a discriminator and a low pass amplifier to obtain the 30 Hz modulation.
- The variable phase signal is similarly amplified by a low pass amplifier.
- The two 30 Hz thus become available and the phase difference between them is to be displayed.
- This is done by a feedback arrangement utilizing a resolver, a phase detector & a motor as shown in figure 1.
- The resolver is a sine cosine generator used to produce an angular phase shift that precisely equivalent to the angular position of its shaft.
- The reference phase signal is given to the resolver and its' output filtered, amplified and applied to the phase detector.
- The variable phase signal is also applied to the phase detector.
- The output of this circuit is a DC voltage, the magnitude and polarity of which depends on the phase difference between the two inputs.
- The dc output goes to a balanced modulator which has a 400 Hz ac switching input, and its output is a 400 Hz voltage, the magnitude and phase of which depend upon the magnitude and polarity of the dc input.
- The ac output is applied, after amplification, to a motor which is coupled to the resolver.
- The feed-back loop is thus completed and the motor turns the resolver until the phase detector output is zero, i.e. until the phase change brought about by the resolver is equal to the phase difference between the reference & variable phase signals.
- The shaft position of the resolver then indicates the phase difference between the reference & variable phase signals, i.e. the direction of the craft with respect to the Omni-range.
- The position of the shaft may be conveyed to any location in the aircraft (e.g. the pilot's control panel by a synchro system.

Range & Accuracy VOR:

- As the operating frequency is in the VHF band, the range of the VOR facility is essentially the line-of-sight range, extended approximately l0-15% by refraction effects.
- The line-of-sight range depends upon the height of the VOR antenna and of the aircraft.
- The useable range is in addition limited by signal/noise considerations and for very high flying aircraft is limited to about 400-500 km.
- For an aircraft flying at 6000 m (20,000 ft), the range is about 335 km.
- The overall error of the VOR system is made up of errors arising from the following sources:
  - a) Ground station and aircraft equipment,
  - b) Site irregularities,
  - c) Terrain features, and
  - d) Polarization
- (a) The Ground Station Equipment error is mainly the octantal error in the installations using two antenna pairs and a rotating goniometer for obtaining the rotating figure-of-eight pattern.
- Octantal error can also arise owing to in homogeneity in the ground characteristics at the installation and could, therefore, occur even where rotating antennas are used.

- ❖ Equipment error in the receiver and indicator in the aircraft arise owing to imperfections of the circuits and components such as those contained in the feed-back control system.
- ❖ The magnitudes of the equipment errors are best specified in terms of the probability distribution.
- ❖ Analysis of a large number of ground station errors indicates that the error distribution is Gaussian, with a 95% probability that the error is within 2°.
- ❖ (b) Site errors arise when the signal arrives at the receiver by two paths, one directly from the range and the other after reflection from objects in the neighbourhood of the range.
- ❖ The reference phase signal is not appreciably affected by this, as the difference in the path delays is always small compared with the period of the modulation cycle.
- ❖ The variable phase components may, however, differ appreciably. Referring to figure 1, the signal arriving directly at the receiver has the variable phase component with a phase difference ϕ_d, with respect to the reference signal while the reflected signal has a phase difference ϕ_r.
- ❖ The carriers of the two signals are also not in phase generally.

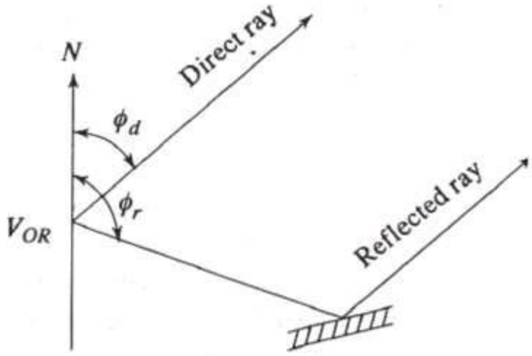


Figure-1 Error due to site irregularity

- ❖ The combination of the two variable phase signals produces, after demodulation, a 30 Hz. signal, the phase of which is different from both ϕ_d & ϕ_r.
- ❖ The magnitude of the error depends upon the relative strengths of the direct and reflected signals as well as upon ϕ_d & ϕ_r.
- ❖ Because of this last quantity, the error varies as the aircraft moves along a radial line, keeping ϕ_d constant resulting in slow bends in the course.
- ❖ Site errors cannot easily be eliminated and, therefore, considerable effort has been devoted to improving the performance of the VOR by refinements of technique.
- ❖ (c) Terrain errors; are those appearing even at considerable distance from the VOR station, owing to the nature of the terrain (e.g. hills, lakes, mountain ranges, etc.) which changes the path of propagation.
- ❖ These errors occur in the immediate vicinity of the interfering objects and appear as rapid fluctuations ('scalloping') in the course-deviation indicator.
- ❖ (d) Polarization error arises because of the vertical component of the radiated electric field, which has a polar diagram different from that of the horizontal component.
- ❖ The error can be reduced by minimizing the vertically polarized component radiated by the ground antenna and by making the aircraft antenna insensitive to vertically polarized signals.
- ❖ The later alone cannot provide a complete solution, because the aircraft has to bank in the course of maneuvers and, however good the antenna, it will then inevitably respond to the vertical field.
- ❖ Suppression of the vertical component from the transmitted radiation is, therefore important particularly for radiation at higher angles.