12

Principles of Radar

12.1 INTRODUCTION

Radar is an electromagnetic system for the detection and location of objects. The word Radar is an abbreviation for Radio detection and Ranging. It operates by transmitting a particular type of waveform and detecting the nature of the signals reflected back from objects. It cannot resolve details or colour. It can see in conditions which do not permit the eye to see such as darkness, haze, rain, smoke. It can also measure the distances to objects. It was radar that gave birth to microwave technology. In fact the early researchers found out that the highest frequencies gave the most accurate results. Higher frequencies produce the best echoes, make it possible to detect smaller targets and permit the use of smaller antennas.

We know that if an electromagnetic wave encounters sudden change in conductivity σ, permittivity ε or permeability μ in the medium, a part of the electromagnetic energy gets absorbed by the second medium and is reradiated. The sudden change in the electrical property of the medium constitutes the target.

Radar was first developed to warm of the approach of hostile aircraft and for directing anti-aircraft weapons.

12.2 BLOCK DIAGRAM OF A SIMPLE RADAR

The elemental radar system consists of a transmitter unit, an antenna for emitting electromagnetic radiation and receiving the echo signal, an energy detecting receiver and a processor. The most basic form of radar is shown in Fig. 12.1. A portion of the transmitted signal is itercepted by a reflecting object (target) and is reradiated in all directions. The antenna collects the returned energy in the back-scatter direction and delivers it to the receiver. The distance to the receiver is determined by measuring the time taken for the electromagnetic signal to travel to the target and back.

12.3 IMPROVED RADAR

A modified block diagram is shown in Fig. 12.2 which has another important block called the duplexer. The functions of a duplexer are:

1. To isolate the transmitter and receiver during transmission and reception.
2. To protect the receiver from high power transmitter and
3. To help use a single transmitter/receiver antenna.

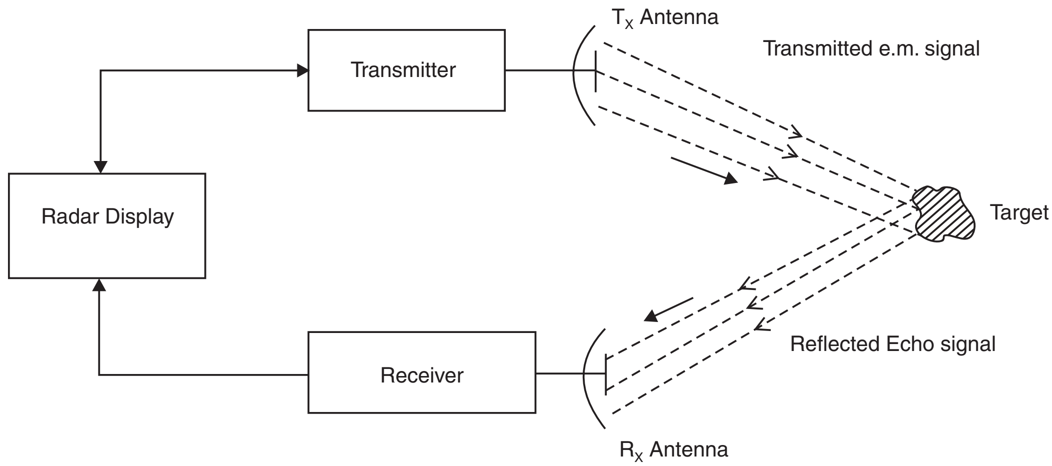

Fig. 12.1 Block diagram of basic radar

Such a radar where a single antenna is used for both transmitting and receiving is called a monostatic radar, which is most usual form of radar.

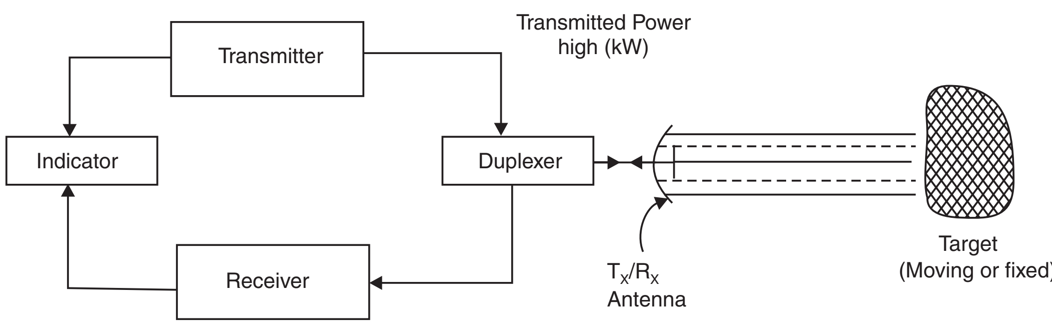

Fig. 12.2 Block diagram of improved radar

12.4 RADAR RANGE EQUATION

The radar range equation relates the range of the radar to the characteristics of the transmitter, receiver, antenna, target and the environment. It is used as a tool to help in specifying radar subsystem specifications in the design phase of a program.

Free space condition implies that the radar set and the target are isolated in an unbounded empty space. The condition is realized well enough for practical purposes if the following conditions are fulfilled:

(*a*) No large obstacles lie between antenna and the target along an optical line of sight.
(*b*) No alternative trasmission path via any reflecting surface can be followed by a substantial fraction of the total radiated energy.
(*c*) The intervening medium is transparent, *i.e.*, it does not absorb energy from the electromagnetic waves at the frequency used.
(*d*) The intervening medium is homogeneous with respect to the refractive index at the radar frequency.

If the transmitter delivers P_T watts power into an isotropic antenna (one which radiates power uniformly in an directions is used), then the power density (W/m^2) at a distance R from the radar is

$$= \frac{P_T}{4\pi R^2} \qquad \text{...(12.1)}$$

here the $4\pi R^2$ represents the surface area of the sphere at distance R. Radars employ directional antennas to channel the radiated power P_T in a particular direction. The gain G_T of an antenna is the measure of the increased power radiated in the direction of the target, compared to the power that would have been radiated from an isotropic antenna. So power density from a directional antenna

$$= \frac{P_T G_T}{4\pi R^2} \qquad \text{...(12.2)}$$

This energy is incident on the target and gets scattered in various directions. A part of the energy returns in the direction of the radar antennas. The target is usually described in terms of an equivalent cross-section σ such that if the total power contained in a section of the incident wavefront having the area σ were radiated by an isotropic radiator located at the target the strength of the radio wave reaching the radar receiving antenna would be the same as the strength of the actual echo produced by target. Area σ is then referred to as the effective echo area of the target.

Hence the power density of the echo signal at the radar

$$= \frac{P_T G_T}{4\pi R^2} \cdot \frac{\sigma}{4\pi R^2} \qquad \text{...(12.3)}$$

The receiving antenna effectively intercepts the power of the echo signal at the radar over a certain area called the effective area A_e.

Since the power density (watts/m^2) is intercepted across an area A_e, the power delivered to the receiver is

$$P_r = \frac{P_T G_T \sigma A_e}{\left(4\pi R^2\right)^2} \text{ watts} \qquad \text{...(12.4)}$$

Equation (12.4) is the free space radar equation.

Now the maximum range $R_{\max}$ is the distance beyond which the target cannot be detected due to insufficient received power P_r. The minimum power which the receiver can detect is called the minimum detectable signal $S_{\min}$.

Setting $P_r = S_{\min}$ and rearranging the above equation gives

$$S_{\min} = \frac{P_T G_T \sigma A_e}{(4\pi)^2 R_{\max}^4} \qquad \text{...(12.5)}$$

or

$$R_{\max} = \left[\frac{P_T G_T \sigma A_e}{(4\pi)^2 S_{\min}}\right]^{1/4} \qquad \text{...(12.6)}$$

Now G_T depends on the type of antenna system used. For a circular paraboloid, as used in microwave radar

$$G_T = \frac{8}{3} \cdot \frac{\pi A_T}{\lambda^2} \qquad \text{...(12.7)}$$

For dipole radiator, the gain gets increased by 50%. Hence effective

$$G_T = \frac{3}{2}\cdot\frac{8}{3}\cdot\frac{\pi A_T}{\lambda^2} = \frac{4\pi A_T}{\lambda^2} \qquad ...(12.8)$$

Hence the circular paraboloid antenna with dipole radiator, Eq. (12.6) giving the free space radar range equation becomes,

$$R_{\max} = \left[\frac{P_T A_e A_T \sigma}{4\pi\lambda^2 S_{\min}}\right]^{1/4} \qquad ...(12.9)$$

Generally the same antenna is used for reception and transmission, so that

$$G_T = G_R = G$$

Where G is given by

$$G = \frac{4\pi A}{\lambda^2} \qquad ...(12.10)$$

Where $A_T = A_e = A$

The equation (12.9) may be written as,

$$R_{\max} = \left[\frac{P_T A^2 \sigma}{4\pi\lambda^2 S_{\min}}\right]^{1/4} \qquad ...(12.11)$$

or

$$R_{\max} = \left[\frac{P_T G^2 \lambda^2 \sigma}{(4\pi)^3 S_{\min}}\right]^{1/4} \qquad ...(12.12)$$

12.5 RADAR PERFORMANCE FACTORS

As seen by the relation for $R_{\max}$ (Eqs. 12.6, 12.11 and 12.12). It is readily observed that $R_{\max}$ depends upon the transmitted power P_T, frequency of the transmitted signal ($\lambda = c/f$), the cross sectional area of the target σ and the minimum receiver signal ($S_{\min}$).

(*a*) **The Range:** Study of equation (12.4) shows that received echo power is inversely proportional to the fourth power of the range R. Thus in order to double the range, a 16-fold increase in peak power P_T is needed. Alternatively, the range may be increased by increasing the physical size of antenna. Equation (12.11) shows that the range $R_{\max}$ varies directly as the square root of the capture area A of the antenna. The range may be increased by reducing the wavelength as is apparent from Eq. (12.12). Lastly the range $R_{\max}$ may be increased by reducing the minimum power $S_{\min}$.

The decrease in $S_{\min}$ may be achieved by improving the noise figure of the radar receiver. This method of improving the range by improving the receiving system is usually cheap and further results in reduction in size and weight than is obtained by increased transmitter power.

If S_i/N_i is the signal to noise ratio at the input of the radar receiver, S_0/N_0 is at the receiver output and G is the overall gain of the receiver (Fig. 12.3). Then noise figure F is given by

$$F = \frac{S_i}{N_i}\Big/\frac{S_0}{N_0} = \frac{S_i}{N_i}\times\frac{N_0}{S_0}$$

i.e. $$F = \frac{S_i}{S_0} \times \frac{N_0}{N_i} \qquad ...(12.13)$$

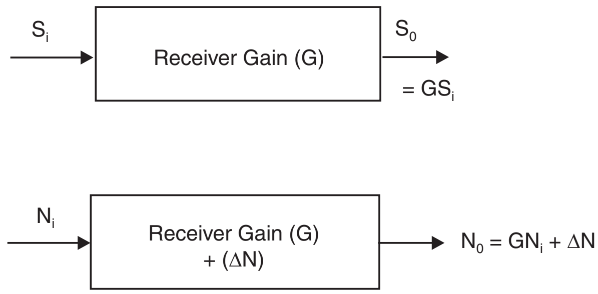

Fig. 12.3

From Fig. (12.3),

$$S_0 = GS_i$$

$$N_0 = (GN_i + \Delta N) \qquad ...(12.14)$$

Where, ΔN = Equivalent noise generated in the receiver.
Substituting for S_0 and N_0 in the Eq. (12.13), we get

$$F = \frac{S_i}{GS_i} \times \left(\frac{GN_i + \Delta N}{N_i} \right)$$

$$= \frac{1}{G} \cdot \left(G + \frac{\Delta N}{N_i} \right)$$

i.e. $$F = 1 + \frac{\Delta N}{GN_i}$$

or $$\Delta N = (F - 1) GN_i \qquad ...(12.15)$$

This is the equivalent noise power generated in the receiver. The input noise power N_i can be expressed in terms of temperature

i.e. $$N_i = KT_0B \qquad ...(12.16)$$

Where, T_0 = temperature in degrees kelvin

K = Boltzmann's constant = 1.38×10^{-23}

and B = bandwidth of the receiver

Substituting for N_i in Eq. (12.15), we get

$$\Delta N = (F - 1)\, G \cdot KT_0B \qquad ...(12.17)$$

If this equivalent noise power at the input of the receiver is more than the minimum received radar echo power S_{min}, then, it is not possible to detect the target data in the receiver. For this to be possible, the minimum received signal at the receiver input, S_{min} must be at least equal to the equivalent noise power, ΔN *i.e.* this is the limit on receiver sensitivity. Substituting ΔN from Eq. (12.17) in Eq. (12.11), we get,

$$R_{max} = \left[\frac{P_T A^2 \sigma}{4\pi\lambda^2 (F-1) KT_0 BG}\right]^{1/4} \quad ...(12.18)$$

For a parabolic antenna,

$$A = \frac{0.65\pi D^2}{4} \quad ...(12.19)$$

Substituting for this, $K = (1.38 \times 10^{-23})$ and $T_0 = (300\text{ K})$, we obtain a practical radar range equation given by,

$$R_{max} = 48\left[\frac{P_T D^4 \sigma}{B\lambda^2 (F-1)}\right]^{1/4} \text{km} \quad ...(12.20)$$

(*b*) **Transmitter Power:** In case the radar range is to be doubled, we have to increase the transmitter power 16 times since $R_{max} \propto (P_T)^{\frac{1}{4}}$.

(*c*) **Frequency:** We know that, $R_{max} \propto 1/\sqrt{\lambda}$ or $R_{max} \propto \sqrt{f}$. This implies that increase in frequency increase the range. However this requirement is in conflict with the dependance of beam width of the antenna which is directly proportional to the wavelength λ.

(*d*) **Pulse Repetition Frequency:** As the pulse repetition frequency (PRF) is increased, the maximum value of two way travel time decreases and hence the maximum range decreases. Thus maximum allowable pulse repetition frequency is limited by the effective range of the radar set. On the other hand, the PRF should not be below certain minimum value so that effective integration of weak echo pulses may take place, due to greater number of pulses received per second.
The range beyond which targets appear as second-time around echos is called "Maximum Unambiguous Range".

$$T = T_R = T_{ON} + T_{OFF} = \frac{1}{PRF} \quad ...(12.21)$$

But

$$R_{max} = \frac{CT}{2} = \frac{C(\text{Max value of } T_R)}{2} \quad ...(12.22)$$

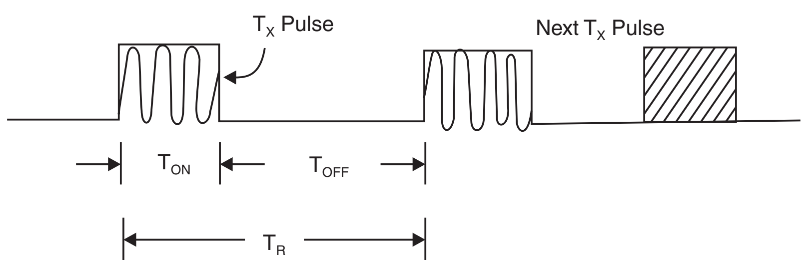

Fig. 12.4

Hence, maximum unambiguous range is given by,

$$R_{\text{unamb}} = \frac{C\left(T_{\text{ON}} + T_{\text{OFF}}\right)}{2} = \frac{C}{2\,PRF} \qquad \text{...(12.23)}$$

Example 12.1. Use the radar range to determine the required transmit power for the TRACS radar given,

$S_{\min} = 10^{-13}$ watts, $G = 2000$, $\lambda = 0.23$ m, PRF = 524 and $\sigma = 2.0$ m^2

Solution: By using equation (12.22),

$$R_{\max} = \frac{C}{2\,PRF} = \left(\frac{3 \times 10^8}{2 \times 524}\right)$$

$$= 286.2 \text{ km.}$$

Now by using Eq. (12.12),

$$P_T = \frac{S_{\min}\,(4\pi)^3 \cdot R_{\max}^4}{G^2 \lambda^2 \sigma}$$

$$= \frac{\left(10^{-13}\right)(4\pi)^3 \left(286.2 \times 10^3\right)^4}{(2000)^2\,(0.23)^2\,(2.0)}$$

$$P_T = 3.1 \text{ MW}$$

12.6 RADAR FREQUENCIES

Most of the radars operate between 220 MHz to 35 GHz, but some special purpose radars operate outside of this range, e.g.

(*a*) Skywave HF-OTH (over the horizon) can operate as low as 4 MHz
(*b*) Groundwave HF Radars operate as low as 2 MHz.
(*c*) Millimeter radars operate up to 95 GHz, and
(*d*) Laser radars (lidars) operate in IR and visible spectrum.

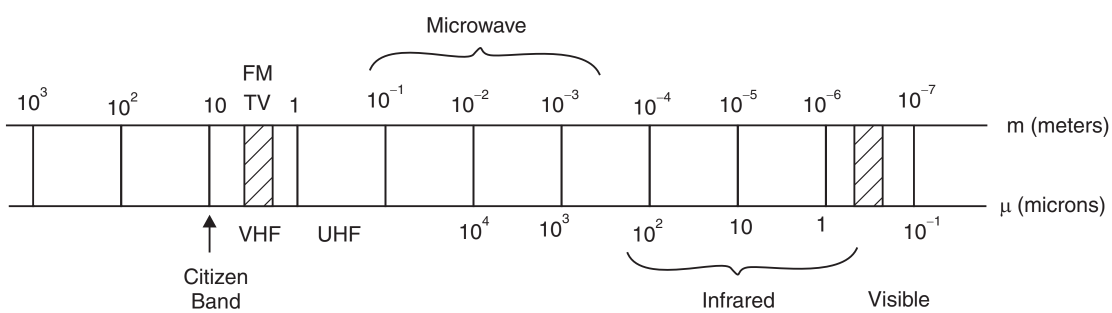

Fig. 12.5 Frequency bands

The radar frequency letter-band nomenclature is shown in table. Note that the frequency assignment to the latter band radar (e.g. L-band radar) is much smaller than the complete range of frequencies assigned to the letter band.

Table 12.1

Band designation	*Nominal frequency range*	*Specific radar bands based on ITU assignments for region 2*
HF	3–30 MHz	
VHF	30–300 MHz	138–144 MHz
		216–225 MHz
UHF	300–1000 MHz	420–450 MHz
		890–942 MHz
L	1000–2000 MHz	1215–1400 MHz
S	2000–4000 MHz	2300–2500 MHz
		2700–3700 MHz
k_u	12–18 GHz	13.4–14.0 GHz
		15.7–17.7 GHz
K	18–27 GHz	24.05–24.25 GHz
k_a	40–300 GHz	33.4–36.0 GHz

12.7 PULSE AND CW RADAR

A pulse radar transmits a sequence of short pulses of RF energy. By measuring the time for echoes of these pulses scattered off a target to return to the radar, the range to the target can be estimated by the pulse radar. The major components of a pulse radar are:

- the transmitter, consisting of an oscillator and a pulse modulator;
- the antenna system, which passes electromagnetic energy from the transmitter to the transmission medium, and receives reflections from the target;
- the receiver, which amplifies the signal received by the pulse radar and detects the returns from targets; and
- interfaces, including displays and interfaces to other electronic systems.

As opposed to pulsed radar systems, continuous wave (CW) radar systems emit electromagnetic radiation at all times. Conventional CW radar cannot measure range because there is no basis for the measurement of the time delay. Recall that the basic radar system created pulses and used the time interval between transmission and reception to determine the target's range. If the energy is transmitted continuously then this will not be possible.

CW radar can measure the instantaneous rate-of-charge in the target's range. This is accomplished by a direct measurement of the Doppler shift of the returned signal. The Doppler shift is a change in the frequency of the electromagnetic wave caused by motion the transmitter, target or both. For example, if the transmitter is moving, the wavelength is reduced by a fraction proportional to the speed it is moving in the direction of propagation. Since the speed of propagation is a constant, the frequency must increase as the wavelength shortens. The net result is an upwards shift in the transmitted frequency, called the Doppler shift.

12.8 INTRODUCTION TO DOPPLER AND M.T.I. RADAR

In general, it is difficult to concern a moving target in the presence of permanent echoes of reasonable size on a radar screen. The trouble gets increased if the moving target has range and bearing in the region of ground clutter. Such difficulties commonly aries in mountainous regions and near cities. To identify separately any moving target we make use the doppler effect.

12.8.1 MTI Radar and Pulse Doppler Radar

A pulse radar that employs the doppler shift for detecting moving targets is either an MTI (moving target indication) radar or pulse doppler radar. The MTI radar has a pulse repetition frequency (PRF) low enough to not have any range ambiguities $R_{un} = c/f_p$. It does, however, have many ambiguities in the doppler domain. The pulse doppler radar, on the other hand, is just the opposite. It has a PRF large enough to avoid doppler ambiguities, but it can have numerous range ambiguities. There is also a medium PRF pulse doppler that accepts both range and doppler ambiguities.

12.8.2 Doppler Effect Associated with Moving Targets

For a fixed target, the relationship between the phases of the transmitted pulse and the echo pulse considered at the site of radar set remains the same for successive pulses. On the other hand, the relative phase of the echo signals received from a moving target continually changes relative to the phase of the transmitted pulse because of the continually changing distance of the target from the radar set. Thus let a moving target move a distance R in time interval dt. This will cause the relative phase of the returned echoes to shift by an amount ϕ radians given by the following relation.

$$\phi = 2 \cdot \frac{2\pi R}{\lambda} = \frac{4\pi R}{\lambda} \qquad \text{...(12.24)}$$

Where λ is the wavelength expressed in the same units as R.

This continuous change in the phase of the echoes received from a radially moving target causes the frequency to the echoes to differ from that of the outgoing pulses. The shift f_d in the frequency, refferred to as the Doppler shift is given by the relation,

$$\omega_d = \frac{d\phi}{dt} = \frac{4\pi}{\lambda} \cdot \frac{dR}{dt} = \frac{4\pi v_r}{\lambda} = 2\pi f_d \qquad \text{...(12.25)}$$

so,

$$f_d = \frac{2 \cdot v_r}{\lambda} = \frac{2 f_t \cdot v_r}{c} \qquad \text{...(12.26)}$$

where $v_r = \dfrac{dR}{dt}$ is the radial velocity (meters/seconds). The rate of change of ϕ with time is the angular frequency $\omega_d = 2\pi f_d$, where f_d is the doppler frequency shift.

12.9 MOVING TARGET INDICATOR (MTI) RADAR

This radar uses the doppler effect for its operation. Many a times it is not possible to distinguish a moving target in the presence of static or permanent echoes of comparable appearance on the radar screen.

In a PPI display, there is a lot of clutter due to these stationary target echoes. Also, it is quite possible that a moving target has a range and bearing such that the echo from the moving target gets superimposed on the ground clutter, such a condition can exist in mountainous region or in close vicinity of modern cities cluttered wall tall buildings.

Basically, the moving target indicator (MTI) system compares a set of received echoes with those received during the previous sweep. Those echoes whose phase has remained constant are then cancelled out. This applies to echoes due to stationary objects, but those due to moving targets do show a phase change; they are thus not canceled nor is noise, for obvious reasons. The fact that clutter due to stationary targets is employed makes it much easier to determine which targets are moving and reduces the time taken by an operator to “take in” the display. It also allows the detection of moving targets whose echoes are hundreds of times smaller than those of nearby stationary targets and which would otherwise have been completely masked. MTI can be used with a radar using a power oscillator (magnetron) output, but it is easier with one whose output tube is a power amplifier.

The effect of dependance on phase of the echo are:

1. targets which are too far away and give only mild echoes are netted in the radar.

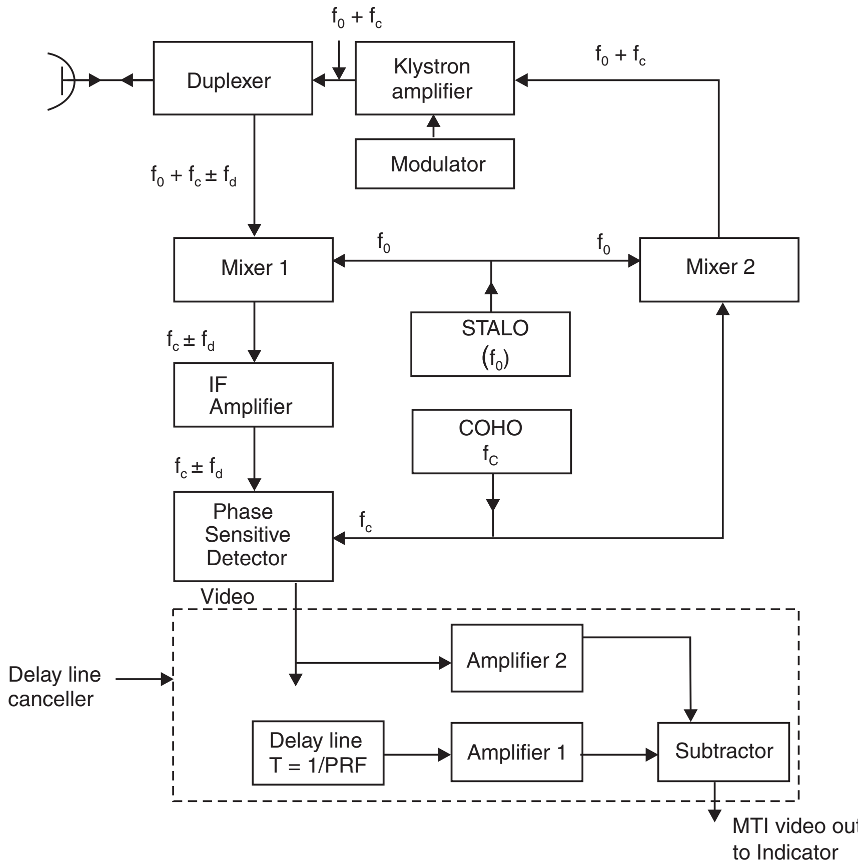

Fig. 12.6 Block diagram of MTI radar using power amplifier output

2. time taken by the radar operator for observing the moving targets is greatly reduced due to elimination of ambiguities and clutter disturbances.
3. stationary or slow moving targets cannot mask the faster ones in the display.

A block diagram of an MTI radar is shown in Fig. 12.6. The block diagram shows two mixers. Mixer 2 generates the transmitter frequency ($f_o + f_c$), which is obtained by the sum of frequencies produced by two oscillators. The first is STALO (stable oscillator) producing f_o and second is the COHO (Coherent oscillator) producing f_c. The transmitted frequency drives a multicavity klystron amplifier, which acts as an output tube. This amplifier provides the desired amplification for proving a high power pulse when modulator switches on the tube. The transmitter pulse is the output via the duplexer.

The echo pulse from the target (due to transmitted pulse) is received by the MTI radar antenna. If the echo is due to a moving target, the echo pulse undergoes a doppler frequency shift. The received echo pulses ($f_o + f_c \pm f_d$) then pass through mixer 1 of the receiver which hytrodynes the received signal of frequency ($f_0 + f_c + f_d$) with the output of STALO at f_0 and produces a difference frequency ($f_c \pm f_d$) at its output. These two mixers 1 and 2 are identical in all respects except that mixer 1 produces a difference frequency whereas mixer 2 produces a sum frequency. This difference frequency signal is further amplified by an IF amplifier and is given to the phase sensitive detector or phase discriminator. This detector compares the IF signal with the reference signal from the COHO oscillator. This difference is the doppler frequency. The detector provides an output depending upon the phase difference between these two signals. Since all received signal pulses will have phase difference compared with the transmitted pulse, the phase detector gives output for both fixed and also for moving targets. Phase difference is constant for all fixed targets but varies for moving targets. Doppler frequency shift causes this variation in phase difference. A change of half cycle in the doppler frequency shift would cause an output of opposite polarity in the phase detector output. The output of the phase detector therefore successive pulses in case of a moving target. However, for fixed targets the magnitude and polarity of the output will remain the same for all transmitted pulses.

In Fig. 12.7 that those returns of each pulse that correspond to stationary targets are identical with each pulse, but those portions corresponding to moving targets keep changing in phase. It is thus possible to subtract the output for each pulse from the preceding one, by delaying the earlier output by a time equal to the pulse interval, or 1/PRF. Since the delay line also attenuates heavily and since signals must be of the same amplitude if permanent echoes are to cancel an amplifier follows the delay line. To ensure that this does not introduce a spurious phase shift, an amplifier is placed in the undelayed line, which has exactly the same response characteristics than amplifier 1. The delayed and undelayed signals are compared in the subtractor, whose output is shown in Fig. 12.7(*d*).

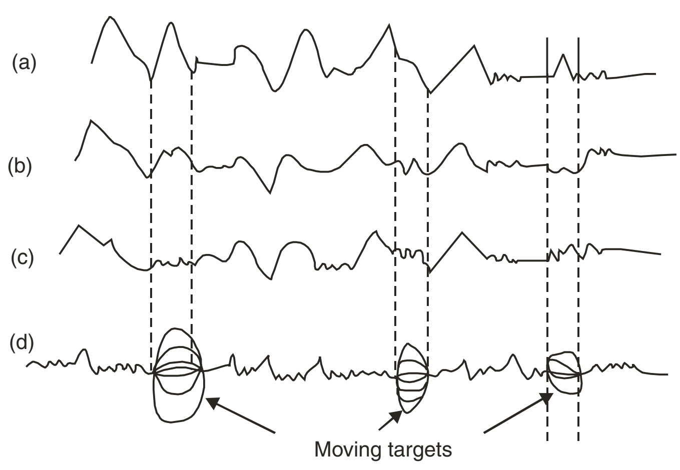

Fig. 12.7 Operation of MTI Radar, (*a*), (*b*), (*c*) phase detector output for three successive pulses; (*d*) subtractor output

12.9.1 Blind Speeds

If the target happens to have a velocity whose radial component results in a phase difference of exactly

2π rad between successive pulses. This is the same as having no phase shift at all. The target thus appears stationary, and echoes from it are canceled by the MTI action. A radial velocity corresponding to this situation is known as a blind speed, as are any integral multiples of it. It is readily seen that if a target moves a half-wavelength between successive pulses, the change in phase shift will be precisely 2π rad. Hence blind speed state that

$$V_b = PRF\frac{n\lambda}{2} \quad ...(12.27)$$

where V_b - blind speed
λ - wavelength of transmitted signal
and n - any integer (1, 2,...)

The target can travel with blind speed, by analysing the transmitted frequency and pulse repetition frequency and adjust its radial velocity as per the analysis. However a variable pulse repetitional frequency decided by a pseudo random generator used by the radar transmitter will solve the problem of blind speed.

Example 12.2. A MTI radar operates at 5 GHz, with a PRF of 800 pps. Calculate the lowest three blind speeds of this radar.

Solution. We know

$$\lambda = \frac{V_c}{f} = \frac{3\times10^8}{5\times10^9} = 0.06\,\text{m}$$

The lowest blind speed corresponds to $n = 1$, therefore

$$V_b = \frac{800\times0.06}{2} = 24 \text{ m/s}$$

$$= 24 \times 60 \times 60 \times 10^{-3} = 86.4 \text{ km/h}$$

12.10 APPLICATIONS OF RADAR

12.10.1 General Applications

1. Ground-based radar is applied chiefly to the detection, location and tracking of aircraft of space targets.
2. Shipborne radar is used as a navigation aid and safety device to locate buoys, shorelines and other ships. It is also used to observe aircraft.
3. Spaceborne radar is used for the remote sensing of terrain and sea, and for redezvous/docking.
4. Airborne radar is used to detect aircraft, ships and land vehicles. It is also used for mapping of terrain and avoidance of thunderstorms and terrain.

12.10.2 Major Applications

1. **Air Traffic Control (ATC):** Radar used to provide air traffic controllers with position and other information on aircraft flying within their area of responsibility (airways and in the vicinity of airports). The high resolution radar is used at large airports to monitor aircraft and ground vehicles on the runways, taxiways and ramps. The GCA (ground controlled approach) or PAR (precision approach radar) provides on operator with high accuracy aircraft position information in both the vertical and horizontal. The operator uses this information to guide the aircraft to a landing in bad

weather. The MLS (microwave landing system) and ATC radar beacon systems are based on radar technology.

2. **Air Navigation:** The weather avoidance radar is used on aircraft to detect and display areas of heavy precipitation and turbulence. Low-flying military aircraft rely on terrain avoidance and terrain following radars to avoid colliding with obstructions or high terrain. Military aircraft employ ground-mapping radars to image a scene. The radio altimeter is also a radar used to indicate the height of an aircraft above the terrain and as a part of self contained guidance system over land.
3. **Ship Safety:** There are one of the least expensive, most reliable and largest applications of radar. Radar is found on ships and boats for collision avoidance and to observe navigation buoys, especially when the visibility is poor. The automatic detection and tracking equipments are available with these radars for collision avoidance. Similarly shore based radars of moderate resolution are used from harbour surveilliance.
4. **Space:** Radars are used for rendezvous and dockign and was used for landing on the moon. The large ground based radars are used for detection and tracking of satellites. The satellite-borne radars used for remote sensing (SAR, Synthetic Aperture Radar).
5. **Remote Sensing:** All radars are remote sensors, and used for sensing geophysical objects (the environment). The radar astronomy are used to probe the moon and planets. The earth resources monitoring radars measure and map sea conditions, water resources, ice cover, agricultural land use, forest conditions, geological formations, environmental pollution (Synthetic Aperture Radar, SAR and Side Looking Airborne Radar, SLAR).
6. **Law Enforcement:** The radar speed meter, familiar to many, is used by police for enforcing speed limits. Radar has been considered for making vehicles safer by warning of ponding collision, actuating the air bag, or warning of obstructions or people behind a vehicle or in the side blind zone. It is also employed for detection of intruders.
7. **Military:** Radar is an important part of air-defence systems as well as the operation of offensive missiles and other weapons. In air defence it performs the functions of surveillance and weapon control. Surveillance includes target detection, target recognition, target tracking, and designation to a weapon system. Weapon-control radars track targets, direct the weapon to an intercept, and assess the effectiveness of the engagement (called battle damage assessment). A missile system might employ radar methods for guidance and fuzing of the weapon. High resolution imaging radars, such as synthetic aperture radar, have been used for reconnaissance purpose and for detecting fixed and moving targets on the battle field.

REVIEW QUESTIONS

1. Explain the basic principles of a radar system. Give the limitations and application of radars.
2. Derive the radar range equation. Explain the factor that affect the maximum range of a radar.
3. How do you distinguish stationary targets and moving targets? Explain the principle and working of an MTI radar.
4. Write on
(*a*) Blind speed (*b*) PRF
5. An MTI radar operates at 8 GHz with a PRF of 3500 PPS. Calculate the lowest three blind speeds of this radar.