1. What is Doppler effect? What are its radar applications?

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, the total number of wavelengths $\lambda$ contained in the two-way path between the radar and the target is $2R/\lambda$. The distance $R$ and the wavelength $\lambda$ are assumed to be measured in the same units. Since one wavelength corresponds to an angular excursion of $2\pi$ radians, the total angular excursion $\phi$ made by the electromagnetic wave during its transit to and from the target is $4\pi R/\lambda$ radians. If the target is in motion, $R$ and the phase $\phi$ are continually changing. A change in $\phi$ with respect to time is equal to a frequency. This is the Doppler angular frequency $\omega_d$ given by

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

$$\frac{4\pi dR}{\lambda} = \frac{4\pi v_r}{\lambda}$$

Where,

$f_d = $ Doppler frequency shift

$v_r = $ relative (or radial) velocity of target with respect to radar.
The Doppler frequency shift is

\[ f_d = \frac{2 \times v_r}{\lambda} = \frac{2 \times v_r \times f_o}{c} \]

where,

- \( f_o \) = transmitted frequency
- \( c \) = velocity of propagation = 3 x 10^8 m/s.

If \( f_d \) is in hertz \( v_r \) in knots, and \( \lambda \) in meters,

\[ f_d = 1.03 \times \frac{v_r}{\lambda} \]

A plot of this equation is shown in Fig. 3.1

Fig. 3.1 Doppler frequency as a function of radar frequency and target relative velocity

The relative velocity may be written \( v_r = v \cos \theta \), where \( v \) is the target speed and \( \theta \) is the angle made by the target trajectory and the line joining radar and target. When \( \theta = 0 \). The Doppler frequency is maximum. The Doppler is zero when the trajectory is perpendicular to the radar line of sight (\( \theta = 90^\circ \)).
2. Draw the block diagram of CW radar and explain its working.

Consider the simple CW radar as illustrated by the block diagram of Fig. 3.2. The transmitter generates a continuous (unmodulated) oscillation of frequency $f_o$, 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 $\pm fd$ as given by $fd = 2\times\frac{v_r}{\lambda}$.

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 $f_0 \pm fd$ enters the radar via the antenna and is heterodyned in the detector (mixer) with a portion of the transmitter signal $f_0$ to produce a doppler beat note of frequency $fd$. The sign of $fd$ is lost in this process.

![Block Diagram](image)

Fig. 3.2 (a) Simple CW radar block diagram; (b) response characteristic of beat-frequency amplifier

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. 3.2h. The low-frequency cutoff must be high enough to reject the 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 centered about the signal frequency. The narrow-bandpass characteristic of the ear results in an effective increase in the signal-to-noise ratio of the echo signal. With subsonic aircraft targets and transmitter frequencies in the middle range of the microwave frequency region, the doppler frequencies usually fall within the passband of the ear. If audio detection were desired for those combinations of target velocity and transmitter frequency which do not result in audible doppler frequencies, the doppler signal could be heterodyned to the audible range. The doppler frequency can also be detected and measured by conventional frequency meters, usually one that counts cycles. An example of the CW radar principle is the radio proximity (VT) fuze, used with great success during World War II for the fusing of artillery projectiles. It may seem strange that the radio proximity fuze should be classified as a radar, but it fulfills the same basic function of a radar, which is the detection and location of reflecting objects by "radio" means.

3. Explain the operation of nonzero Intermediate-frequency receiver with block diagram.

The receiver of the simple CW radar is in some respects analogous to a superheterodyne receiver. Receivers of this type are called homodyne receivers, or superheterodyne receivers with zero IF. The function of the local oscillator is replaced by the leakage signal from the transmitter. Such a receiver is simpler than one with a more conventional intermediate frequency since no IF amplifier or local oscillator is required. However, 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. Thus, at the lower range of frequencies (audio or video region), where the doppler frequencies usually are found, the detector of the CW receiver can introduce a considerable amount of flicker noise, resulting in reduced receiver sensitivity. For short-range, low-power, applications this decrease in sensitivity might be tolerated since it can be compensated by a modest increase in antenna aperture and/or additional transmitter power. But for 'maximum efficiency with CW radar, the reduction in sensitivity caused by the simple doppler receiver with zero IF, cannot be tolerated.

The effects of flicker noise are overcome in the normal superheterodyne receiver by using an intermediate frequency high enough to render the flicker noise small compared with the normal receiver noise. This results from the inverse, frequency dependence of flicker noise.
Figure 3.4 shows a block diagram of the CW radar whose receiver operates with a nonzero IF. Separate antennas are shown for transmission and reception instead of the usual local oscillator found in the conventional superheterodyne receiver, the local oscillator (or reference signal) is derived in this 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 superheterodyne might be as much as 30 dB over simple receiver.

Fig. 3.3 Block diagram of CW doppler radar with nonzero IF receiver, sometimes called sideband superheterodyne

4. Explain with necessary block diagram, how doppler direction is identified with CW radar.

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. 3.4.

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

\[ E_A = K_2 E_0 \cos (\pm \omega_d t + \phi) \]

\[ E_A = \text{amplitude of transmitter signal} \]

\[ K_2 = \text{a constant determined from the radar equation} \]
The other channel is similar, except for a 90° phase delay introduced in the reference signal. The output of the channel B mixer is

$$E_B = K_2 \ E_0 \ \cos \left( \pm w_d t + \varphi + \frac{\pi}{2} \right)$$

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

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

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

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

The sign of $w_d$ 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.

Electronic methods may be used instead of a synchronous motor to sense the relative phase of the two channels. One application of 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. It has also been applied to the detection of moving targets in the presence of heavy foliage.
5. Explain the operation of CW tracking illuminator.

Some anti-air-warfare guided missile systems employ semiactive homing guidance in which a receiver in the missile receives energy from the target, the energy having been transmitted from an "illuminator" external to the missile. The illuminator, for example, might be at the launch platform. CW illumination has been used in many successful systems. An example is the Hawk tracking illuminator. It is a tracking radar as well as an illuminator since it must be able to follow the target as it travels through space.

The Doppler discrimination of a CW radar allows operation in the presence of clutter and has been well suited for low altitude missile defense systems. A block diagram of a CW tracking illuminator is shown in Fig. 3.5.

The operation in presence of clutter is possible, due to the Doppler discrimination of continuous wave radar. In this type of radar, the receiver in the missile receives the energy from the target and this energy has been transmitted to the missile by an illuminator. The illuminator may be at the launch platform. This CW illuminator has been used in many successful systems.

The wide-band doppler amplifier is a speed gate, which is a narrow-band tracking filter that acquires the target's Doppler and tracks its changing Doppler frequency shift.
6. What are the Applications of CW radar?

Applications of CW radar:

1. The chief use of the simple, unmodulated CW radar is for the measurement of the relative velocity of a moving target, as in the police speed monitor or in the previously mentioned rate-of-climb meter for vertical-take-off aircraft.

2. In support of automobile traffic, CW radar has been suggested for the control of traffic lights, regulation of tollbooths, 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 to replace the conventional axle-driven tachometer. In such an application it would be unaffected by errors caused by wheelslip on accelerating or wheelslide when braking.

4. It has been used for the measurement of railroad-freight-car velocity during humping operations in marshalling yards, and as a detection device to give track maintenance personnel advance warning of approaching trains.

5. CW radar is also employed for monitoring the docking speed of large ships.
6. It has also seen application for intruder alarms and for the measurement of the velocity of missiles, ammunition, and baseballs.

7. The principal advantage of a CW doppler radar over other (nonradar) methods of measuring speed is that there need not be any physical contact with the object whose speed is being measured.

8. 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.

9. 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.

7. **What is the purpose of filter banks in CW radar receivers. Draw the block diagram of IF Doppler filter bank.**

A relative wide band of frequencies called a 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. 3.7) 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 needed. The center 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 foldover, 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 foldover in the video is that only half the number of filters are required than in the IF filter bank.
8. Explain the operation of side band superheterodyne type CW Doppler radar with block diagram.

Refer question 3

9. Derive an expression for the relative velocity of the target in CW radar.

Let $R$ be the distance from the radar to target.

Then the total number of wavelengths $\lambda$ contained in the two-way path between the radar and the target is $2R / \lambda$. The distance $R$ and the wavelength $\lambda$ are assumed to be measured in the same units.
Since one wavelength corresponds to an angular excursion of $2\pi$ radians, the total angular excursion $\phi$ made by the electromagnetic wave during its transit to and from the target is $4\pi R / \lambda$ radians.

$$\phi = \frac{4\pi R}{\lambda} \text{ radians}$$

If the target is in motion, $R$ and the phase $\phi$ are continually changing. A change in $\phi$ with respect to time is equal to a frequency. This is the doppler angular frequency $\omega_d$ given by

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

$$= \frac{4\pi dR}{\lambda} = \frac{4\pi v_r}{\lambda}$$

Where,

$f_d$ = Doppler frequency shift and

$v_r$ = relative (or radial) velocity of target with respect to radar.

The Doppler frequency shift is

$$f_d = 2* v_r / \lambda$$

$$= 2* v_r * f_o / c$$

Where,

$f_o$ = transmitted frequency

$c$ = velocity of propagation = $3 \times 10^8$ m/s.

Thus the expression for relative velocity of the target with respect to radar is given by

$$v_r = \frac{f_d \cdot c}{2 f_o}$$

10. What is the importance of providing isolation between transmitter and receiver?

A single antenna serves the purpose of transmission and reception in the simple CW radar. In principle, a single antenna may be employed since the necessary 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. If a leakage signal of sufficient
magnitude were not present, a sample of the transmitted signal would have to be deliberately introduced into the receiver to provide the necessary reference frequency.

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, microphonics, stray pick-up, and instability which enters the receiver from the transmitter. The additional noise introduced by the transmitter reduces the receiver sensitivity. Except where the CW radar operates with relatively low transmitter power and insensitive receivers, additional isolation is usually required between the transmitter and the receiver if the sensitivity is not to be degraded either by burnout or by excessive noise.

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. For example, if the safe value of power which might be applied to a receiver were 10 mW and if the transmitter power were 1 kW, the isolation between transmitter and receiver must be at least 50 dB.

The amount of isolation needed in a long-range CW radar is more often determined by the noise that accompanies the transmitter leakage signal rather than by any damage caused by high power. For example, suppose the isolation between the transmitter and receivers were such that 10 mW of leakage signal appeared at the receiver. If the minimum detectable signal were $10^{-13}$ watt (100 dB below 1 mW), the transmitter noise must be at least 110 dB (preferably 120 or 130 dB) below the transmitted carrier.

The amount of isolation which can be readily achieved between the arms of practical hybrid junctions such as the magic-T, rat race, or short-slot coupler is of the order of 20 to 30 dB.

An important factor which limits the use of isolation devices with a common antenna is the reflections produced in the transmission line by the antenna.