UNIT- III

CONTINUOUS WAVE RADAR

3.1. Introduction

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 $\mathbf{10^{-18}}$ 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.

3.2. Doppler Shift

Doppler is the apparent change in wavelength (or frequency) of an electromagnetic or acoustic wave when there is relative movement between the transmitter (or frequency source) and the receiver.

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

$$\Phi = 2 \times 2\pi \times R/\lambda = 4\pi R/\lambda$$

Where $\boldsymbol{\Phi}$ is total phase shift of the signal during transit time

$$\omega_d = 2\pi f_d = d\Phi/dt = 4\pi/\lambda \; dR/dt = (4\pi/\lambda)\, V_r$$

Where 'ω_d' is Doppler angular frequency and 'f_d'is the Doppler frequency
v_r is the relative radial velocity of the target

$$f_d = 2 V_r / \lambda$$

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 i.e. $\theta = 90^0$

The CW radar which employs a continuous transmission, either modulated or un-modulated is of interest not only because of its many applications, but its study also serves as a means for better understanding the nature and use of the doppler information contained in the echo signal, whether in a CW or a pulse radar (MTl) application. In addition to allowing the received signal to be separated from the transmitted signal, the CW radar provides a measurement of relative velocity which may be used to distinguish moving targets from stationary objects or clutter.

3.3. CW Radar

Consider the simple CW radar as illustrated by the block diagram of Fig. **3.1.** The transmitter generates a continuous (un-modulated) oscillation of frequency f_o, which is radiated by the antenna through a circulator. 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 $\pm f_d$ as given by Eq. (3.2). 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 $f\pm f_d$ 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 f_d. The sign of. f_d is lost in this process.

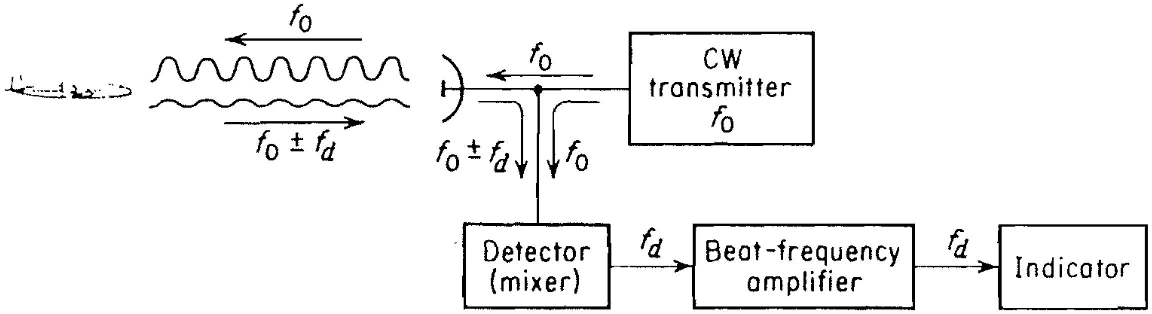

Figure 3.1 Simple CW radar block diagram

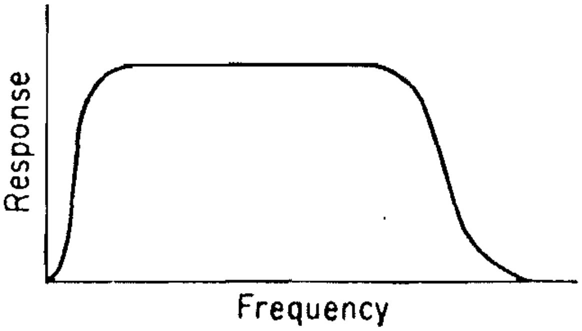

Figure 3.2 Response characteristic of beat-frequency amplifier.

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. *3.2.* The low-frequency cutoff must be high enough to reject tile d-c component caused by stationary targets, but **yet it must be low enough to pass the smallest doppler frequency expected**.

Sometimes both conditions cannot he met simultaneously and a compromise is necessary. The upper cutoff frequency is selected to pass the highest doppler frequency expected. The design of Doppler frequency amplifier is a challenge to design engineers.

3.4. Isolation between transmitter and receiver

A single antenna serves the purpose of transmission and reception in the simple CW radar described above. 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.

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 tile 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.

It will be recalled from previous chapter that the receiver of a pulsed radar is isolated and protected from the damaging effects of the transmitted pulse by the duplexer, which short-circuits the receiver input during the transmission period. Turning off the receiver during transmission with a duplexer is not possible in a CW radar since the transmitter is operated continuously. **Isolation between transmitter and receiver might be obtained with a single antenna by using a hybrid junction, circulator, turnstile junction, or with separate polarizations.** Separate antennas for transmitting and receiving might also be used. 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. In some instances, when extreme precision is exercised, an isolation of perhaps 60 dB or more might be achieved. One limitation of the hybrid junction is the 6-dB loss in overall performance which results from the inherent waste of half the transmitted power and half the received signal power.

Ferrite isolation devices such as the circulator do not suffer the 6-dB loss inherent in the hybrid junction. Practical devices have isolation of the order of 20 to 50 dB.

3.5. Intermediate-frequency Receiver. (Zero IF Receiver)

The receiver of the simple CW radar of Fig. 3.1 is in some respects analogous to a super-heterodyne receiver. Receivers of this type 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. 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.*** 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 compensate by a modest increase in antenna aperture and/or additional transmitter power. But for maximum efficiency with CW radar, the reduction in the sensitivity caused by the simple Doppler receiver with zero IF, cannot be tolerated.

The effects of flicker noise are overcome in the normal super-heterodyne 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 3.3 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 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 of Fig. 3.1.

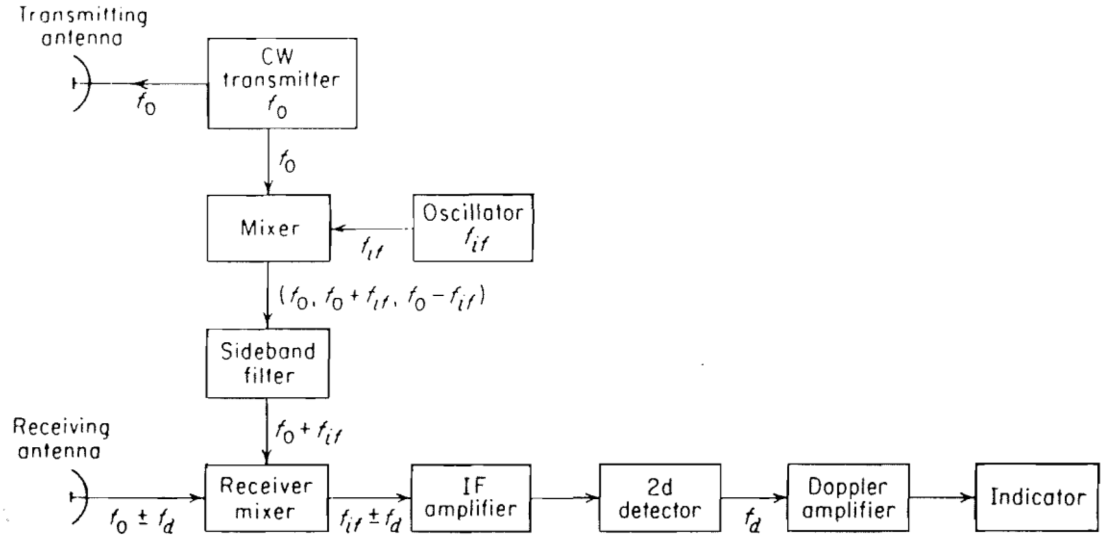

Figure 3.3 Block diagram of CW doppler radar with nonzero IF receiver,

3.6. Receiver bandwidth

One of the requirements of the doppler-frequency amplifier in the simple CW radar (Fig. 3.2) or the IF amplifier of the sideband super-heterodyne (Fig. 3.3) 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. Consequently, 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, a narrowband filter-one just wide enough to reduce the excess noise without eliminating a significant amount of signal energy-might be used. If the waveform of the echo signal were known, as well as its carrier frequency, the matched filter could be specified, which will be discussed at depth in subsequent chapters.

Several factors tend to spread the CW signal energy over a finite frequency band. These must be known if an approximation to the bandwidth required for the narrowband Doppler filter is to be obtained.

If the received waveform were a sine wave of infinite duration, its frequency spectrum would be a delta function (Fig. 3.5a) 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. 3.5b). Practical receivers can only approximate this characteristic. (Note that this is the same as the Spectrum of a pulse of sine wave, the only difference being the relative value of the duration δ) 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.

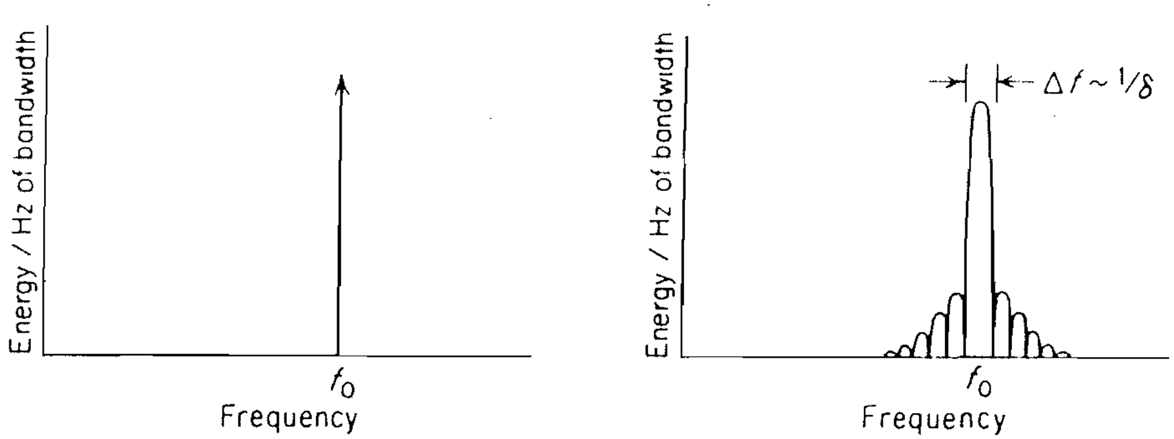

Figure 3.5 Frequency spectrum of CW oscillation of (a) infinite duration and (b) finite duration.

Assume a **CW** radar with an antenna beamwidth of θ_B, deg scanning at the rate of $d\theta_S/dt$ deg/s. The time on target (duration of the received signal) is $\delta = \theta_B,/(d\theta_S/dt)$. 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 $d\theta_S/dt /(\theta_B)$.,. Although this is not an exact relation, it is a good enough approximation for purposes of the present discussion. If the antenna beamwidth 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.

3.7. Sign of the radial velocity.

In some applications of CW radar it is of interest to know whether the target is approaching or receding. This might be determined with separate filters located on either side of the intermediate frequency. If the echo-signal frequency lies below the carrier, the target is receding; if the echo frequency is greater than the carrier, the target is approaching (Fig. 3.6). Although the doppler-frequency spectrum "folds over" in the video because of the action of the detector, it is possible to determine its sign from a technique borrowed from single-sideband communications. If the transmitter signal is given by

$$E_t = E_0 \cos \omega_o t$$

the echo signal from a moving target will be

$$E_r = k_1 E_0 \cos \{ (\omega_o \pm \omega_d)t + \Phi \}$$

where E_o = amplitude of transmitter signal
k_1 = a constant determined from the radar equation
ω_o = angular frequency of transmitter, rad/s
ω_d = dopper angular frequency shift
Φ = a constant phase shift, which depends upon range of initial detection

The sign of the doppler frequency, and therefore the direction of target motion, may be found *I* by splitting the received signal into two channels as shown in Fig. 3.7. In channel **A** the signal is processed as in the simple CW radar of Fig. 3.2. The received signal and a portion of the transmitter heterodyne in the detector (mixer) to yield a difference signal

$$E_A = k_2 E_0 \cos\{\pm \omega_d t + \Phi\}$$

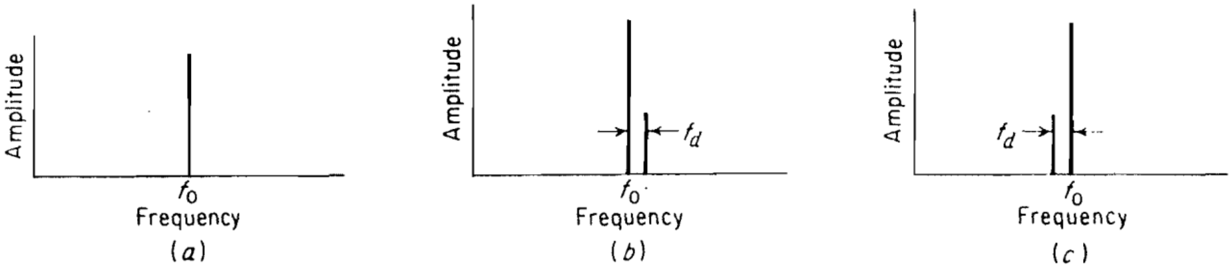

Figure 3.6 Spectra of received signals. (a) No doppler shift, no relative target motion; (b) approaching target; (c) receding target.

The other channel is similar, except for a 90^0 phase delay introduced in the reference signal. The output of the channel B mixer is

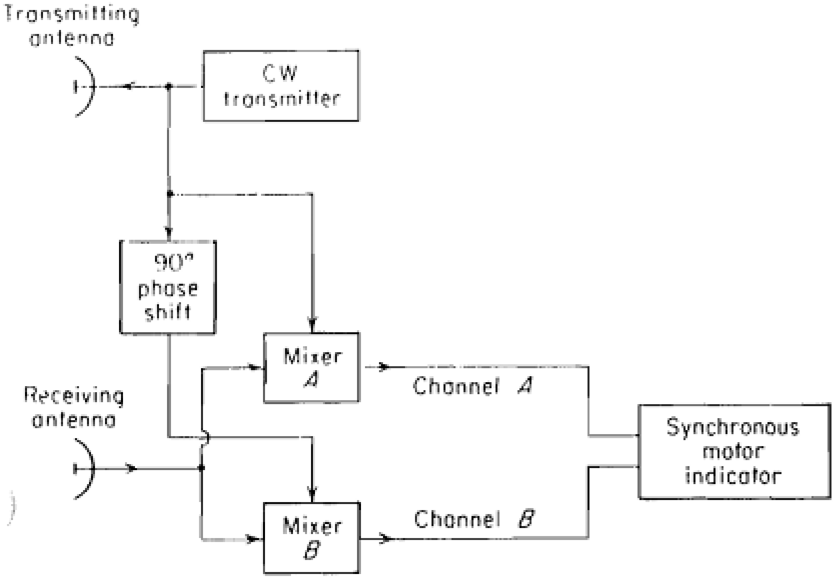

Figure 3.7: Measurement of doppler direction using synchronous, two-phase motor.

$$E_B = k_2 E_0 \cos\{\pm \omega_d t + \Phi + \pi/2\}$$

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

$$E_A(+) = k_2 E_0 \cos\{\omega_d t + \Phi\}$$

$$E_B(+) = k_2 E_0 \cos\{\omega_d t + \Phi + \pi/2\}$$

On the other hand, if the targets are receding (negative doppler),

$$\mathbf{E_A(-) = k_2 E_0 \cos\{ \omega_d t - \Phi \}}$$

$$\mathbf{E_B(-) = k_2 E_0 \cos\{ \omega_d t - \Phi - \pi/2 \}}$$

The sign of ω_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.

3.8. Applications of CW radar.

The chief use of the simple, un-modulated CW radar is for

(a) The measurement of the relative velocity of a moving target, as in the police speed monitor.
(b) Rate-of-climb meter for vertical-take-off aircraft.

(c) In support of automobile traffic, CW radar has been suggested for the control of traffic lights, regulation of toll booths, vehicle counting, as a replacement for the " fifth-wheel" speedometer in vehicle testing.

(d) As a sensor in antilock braking systems, and for collision avoidance for railways.

(e) CW radar can be used as a speedometer to replace the conventional axle-driven tachometer.

(f) CW radar is also employed for monitoring the docking speed of large ships.

(g) It has also seen application for intruder alarms and for the measurement of the velocity of missiles, ammunition, and baseballs.

One of the greatest shortcomings of the simple CW radar is its inability to obtain a measurement of range. This limitation can be overcome by modulating the CW carrier, as in the frequency-modulated radar described in the next section.

Solve Problems

1. *The operating frequency of the radar is 3 G Hz. If the relative velocity of the target is 500 kmph, find out the Doppler shift .*

$$f_d = 2\mathbf{V_r} / \lambda = 2v_r f / c = \frac{2 \times 500 \times 10^3 \times 3 \times 10^9}{3 \times 10^8 \times 3600} = 2.777 \text{ k Hz}$$

2. With a (CW) transmit frequency of 5 GHz, calculate the Doppler frequency seen by a stationary radar when the target radial velocity is 100km/h(62.5mph). [JNTU May 2012]

$$f_d = 2\,\mathbf{V_r} / \lambda = 2v_r f / c = \frac{2 \times 100 \times 10^3 \times 5 \times 10^9}{3 \times 10^8 \times 3600} = 0.925 \text{ k Hz}$$

3. The transmitter power is 1 KW and safe value of power which might be applied to a receiver is 10mW. Find the isolation between transmitter and receiver in dB. Suggest the appropriate isolator. [JNTU May 2012]

Isolation= 10 log [1 kw/10mW] = 10 log [$10^3/10^{-2}$] = 10 log 10^5 = >50 dB

4. Determine the angular frequency if the target is moving with a velocity of 2km/h and operating wavelength is 4cms. [JNTU May 2010]

$$\text{Angular Frequency} = \omega_d = 4\pi \mathbf{V_r} / \lambda = [4\pi \times 2 \times 10^3] / [4 \times 10^{-2} \times 3600] = 174 \text{ rad/s}$$

5. Calculate Doppler frequency shift (f_d) when the relative velocity of target with respect to radar is 50 knots at a transmitted frequency of 80MHZ. [JNTU Jan 2010]

1 knot = 1.852 km/h
50 knots= 92.6 km/h

$$f_d = 2\,\mathbf{V_r} / \lambda = 2v_r f / c = \frac{2 \times 92.6 \times 10^3 \times 80 \times 10^6}{3 \times 10^8 \times 3600} = 13.71 \text{ Hz}$$

Essay type questions

1. Derive the expression for the relative velocity of a target with respect to radar from Doppler frequency. [JNTU May 2012]
2. Explain how the Doppler direction is measured using synchronous two phase modulator? [JNTU May 2012]
3. Draw the block diagram and explain the operation of a CW Doppler radar using an intermediate frequency in the receiver. How have the drawbacks of the basic CW radar been overcome? [JNTU May 2012]
4. Explain how earphones are used as an indicator in CW Radar? [JNTU May 2012]
5. Explain how the sign of the Doppler frequency is found by splitting the received signal in CW radar? [JNTU May 2011]
6. Drive the expression for doppler frequency and plot it as a function of radar frequency and target radial velocity. Assume necessary parameters. [JNTU May 2011]
7. Draw the block diagram and explain the operation of a CW Doppler radar using an intermediate frequency in the receiver. How have the drawbacks of the basic CW radar been overcome? [JNTU May 2011]
8. What is the Doppler effect? Explain how it is used in CW Radar? [JNTU May 2011]
9. Explain why isolation between transmitter and receiver is required in the CW Radar? What are the devices used for isolation? [JNTU May 2011]

10. Draw the block diagram of IF Doppler filter bank? Draw its frequency response characteristics? [JNTU Jan 2010]
11. What are the different methods that provide isolation between transmitter and receiver? [JNTU Jan 2010]
12. Draw the block diagram of a simple CW radar and explain the working of each block? Explain about transmitter clutter. [JNTU Jan 2010]
13. Explain about the Doppler effect? What are effects of receiver bandwidth in CW radar? [JNTU Jan 2010]
14. Explain the operation of CW Doppler radar non zero IF with neat block diagram. [JNTU May 2009]

Objective type questions

1. In a CW radar [ ]

A. Transmission & reception takes place simultaneously
B. Reception takes place after transmission is over
C. Transmission is only for short duration
D. None of the above

2. The sign of doppler frequency shift depends upon [ ]

A. Phase of transmitted signal
B. Reference frequency
C. Direction of rotation of antenna
D. Direction of relative velocity of target

3. The doppler filter in a CW radar is primarily a [ ]

A. Low Pass Filter
B. High Pass Filter
C. Band Pass Filter
D. Band Elimination Filter

4. The doppler frequency shift is proportional to [ ]

A. Operating frequency
B. PRF
C. Relative velocity of target
D. Both A & C above

5 The doppler frequency shift caused by an aircraft circling at a speed of 100 m/sec around a radar operating at frequency of 3 G Hz is [ ]

A. 2 kHz
B. 20 kHz
C. Zero
D. 2 MHz

6. In a CW radar receiver the Local Oscillator is replaced by [ ]

A. Second detector
B. High accuracy mixer
C. Band pass filter
D. Transmitted signal feedback

7. The flicker noise in radar receiver increases with [ ]

A. Increase in Intermediate frequency
B. Decrease in Intermediate frequency
C. Increase in radar frequency
D. Both A & C above

8. A duplexer is used to [ ]

A. Couple two antennas to a transmitter without interference
B. Isolate the antenna from the local oscillator

C.	Prevent interference between two antennas connected to a receiver	D.	Use single antenna for reception and transmission without interference

9. Zero Intermediate frequency of CW radars causes [ ]

A.	Thermal noise	B.	Cancellation noise
C.	Flicker noise	D.	None of the above

Answers

Q.No.	Answer	Q.No.	Answer
1	A	8	D
2	D	9	C
3	C		
4	D		
5	C		
6	D		
7	B		

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