DEPT & SEM	:	ECE & I SEM
SUBJECT NAME	:	RADAR SYSTEMS
COURSE CODE	:	RS
UNIT	:	II
PREPARED BY	:	Y.SREENIVASULA GOUD

UNIT 2-CW AND FREQUENCY MODULATED RADAR

- Doppler Effect
- CW Radar-Block diagram
- Isolation between transmitter and receiver
- Non-Zero IF Receiver
- Receiver Bandwidth Requirement
- Application of CW radar
- Illustrative problems

UNIT 2-FW-CW RADAR

- **Range and Doppler Measurement**
- **Block diagram and characteristics**
- **FM-CW altimeter**
- **Multiple Frequency CW radar**

DOPPLER EFFECT

In this chapter, we will learn about the Doppler Effect in Radar Systems.
If the target is not stationary, then there will be a change in the frequency of the signal that is transmitted from the Radar and that is received by the Radar. This effect is known as the **Doppler effect.**
According to the Doppler effect, we will get the following two possible cases:

- The **frequency of the received signal will increase, when the target moves towards the direction of the Radar.**
- The **frequency of the received signal will decrease, when the target moves away from the Radar.**

Now, let us derive the formula for Doppler frequency.

Derivation of Doppler Frequency

The distance between Radar and target is nothing but the Range of the target or simply range, R. Therefore, the total distance between the Radar and target in a two-way communication path will be 2R, since Radar transmits a signal to the target and accordingly the target sends an echo signal to the Radar.

If λ is one wave length, then the number of wave lengths N that are present in a two-way communication path between the Radar and target will be equal to $2R/\lambda$

We know that one wave length λ corresponds to an angular excursion of 2π radians. So, the total angle of excursion made by the electromagnetic wave during the two-way communication path between the Radar and target will be equal to $4\pi R/\lambda$ radians.

Following is the mathematical formula for **angular frequency**, ω:

$$\omega = 2\pi f \qquad \text{Equation 1}$$

Following equation shows the mathematical relationship between the angular frequency ω and phase angle $\emptyset$:

$$\omega = \frac{d\emptyset}{dt} \qquad \text{Equation 2}$$

Equate the right hand side terms of Equation 1 and Equation 2 since the left hand side terms of those two equations are same.

$$2\pi f = \frac{d\emptyset}{dt}$$

$$=> f = \frac{1}{2\pi} \cdot \frac{d\emptyset}{dt} \qquad \text{Equation 3}$$

Substitute, $f = f_d$ and $\emptyset = 4\pi R/\lambda$ in Equation 3.

$$f_d = \frac{1}{2\pi} \cdot \frac{d}{dt}\left(\frac{4\pi R}{\lambda}\right)$$

$$=> f_d = \frac{1}{2\pi} \cdot \frac{4\pi}{\lambda}\frac{dR}{dt}$$

$$=> f_d = \frac{2V_r}{\lambda} \qquad \text{Equation 4}$$

Where,

f_d is the Doppler frequency

V_r is the relative velocity

We can find the value of Doppler frequency f_d by substituting the values of V_r and λ in Equation 4.

$$f_d = \frac{2V_r}{(C/f)}$$

$$=> f_d = \frac{2V_r f}{C} \quad \text{Equation 5}$$

Where,

f is the frequency of transmitted signal

C is the speed of light and it is equal to $3 \times 10^8 m/sec$

We can find the value of Doppler frequency, f_d by substituting the values of V_r, f and C in Equation 5.

Note: Both Equation 4 and Equation 5 show the formulae of Doppler frequency, f_d. We can use either Equation 4 or Equation 5 for finding **Doppler frequency**, f_d based on the given data.

DOPPLER EFFECT

- The relative velocity may be written *vr = v cos ϑ, 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°)

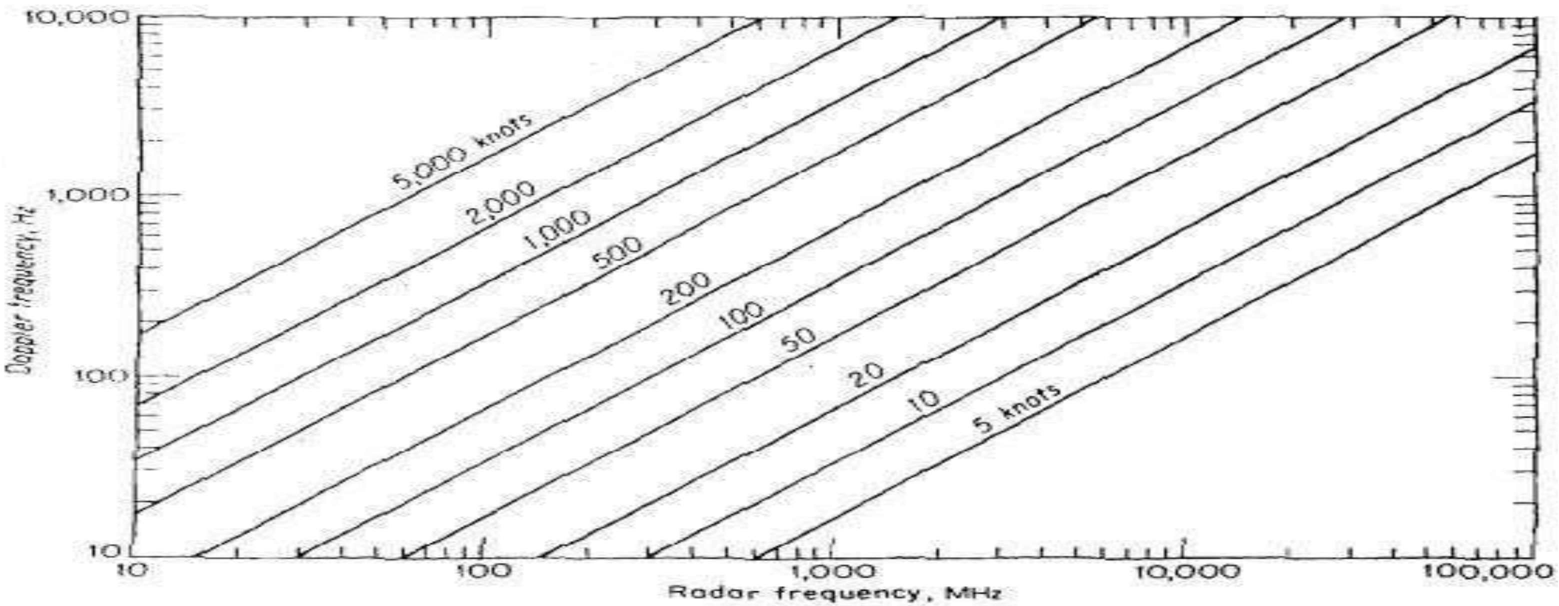


Fig.2.1 Doppler frequency fd as a function of radar frequency and target relative velocity.

Example Problem

If the Radar operates at a frequency of $5GHz$, then find the **Doppler frequency** of an aircraft moving with a speed of 100KMph.

Solution

Given,

The frequency of transmitted signal, $f = 5GHz$

Speed of aircraft (target), $V_r = 100KMph$

$$=> V_r = \frac{100 \times 10^3}{3600} m/sec$$

$$=> \boldsymbol{V_r = 27.78m/sec}$$

We have converted the given speed of aircraft (target), which is present in KMph into it equivalent m/sec.

We know that, the speed of the light, $C = 3 \times 10^8 m/sec$

Now, following is the **formula for Doppler frequency**:

$$f_d = \frac{2V_r f}{C}$$

Substitute the values of V_r, f and C in the above equation.

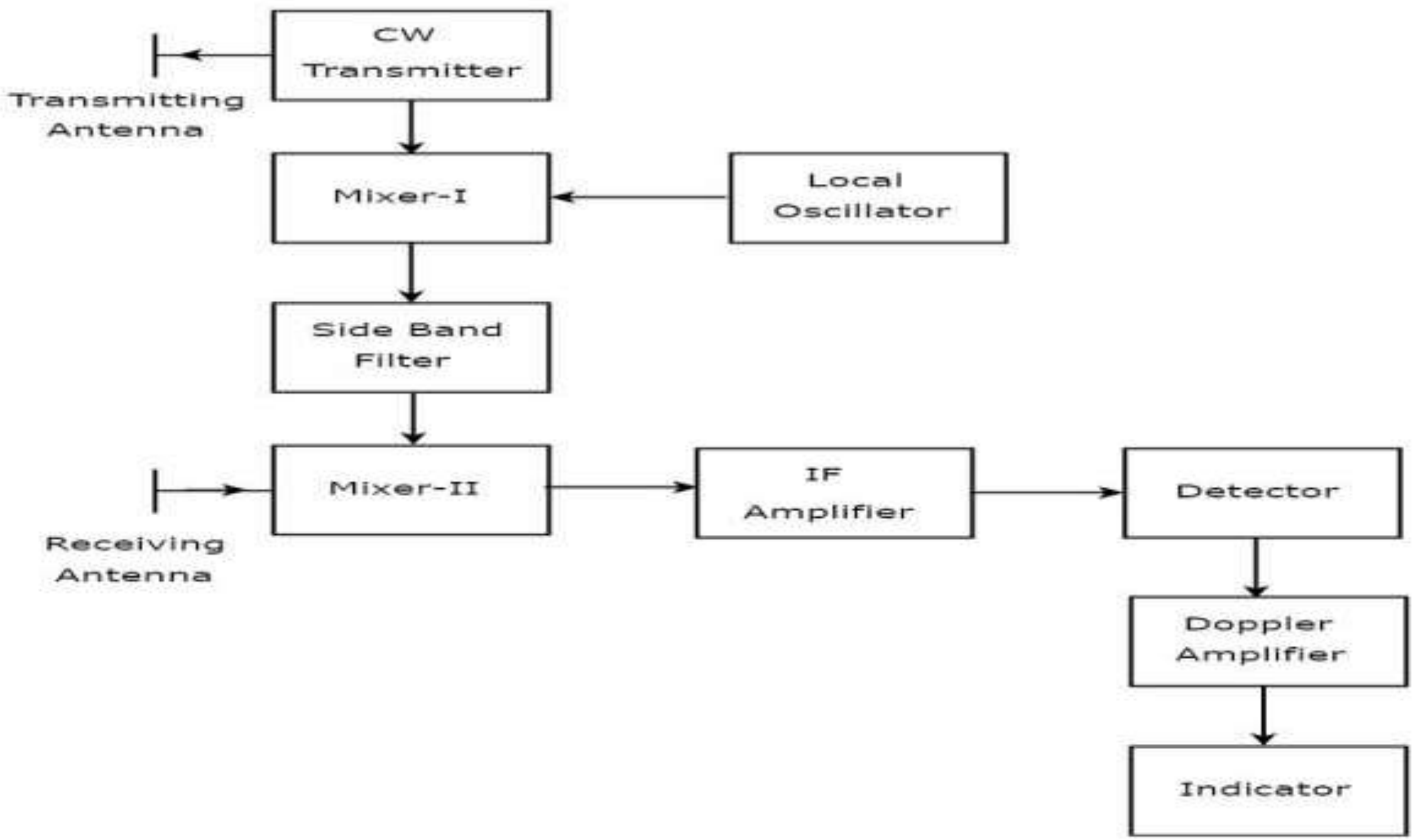
$$=> f_d = \frac{2(27.78)(5 \times 10^9)}{3 \times 10^8}$$

$$=> f_d = 926Hz$$

Therefore, the value of **Doppler frequency**, f_d is $\boldsymbol{926Hz}$ for the given specifications.

Block Diagram of CW Radar

We know that CW Doppler Radar contains two Antennas — transmitting Antenna and receiving Antenna. Following figure shows the **block diagram of CW Radar:**



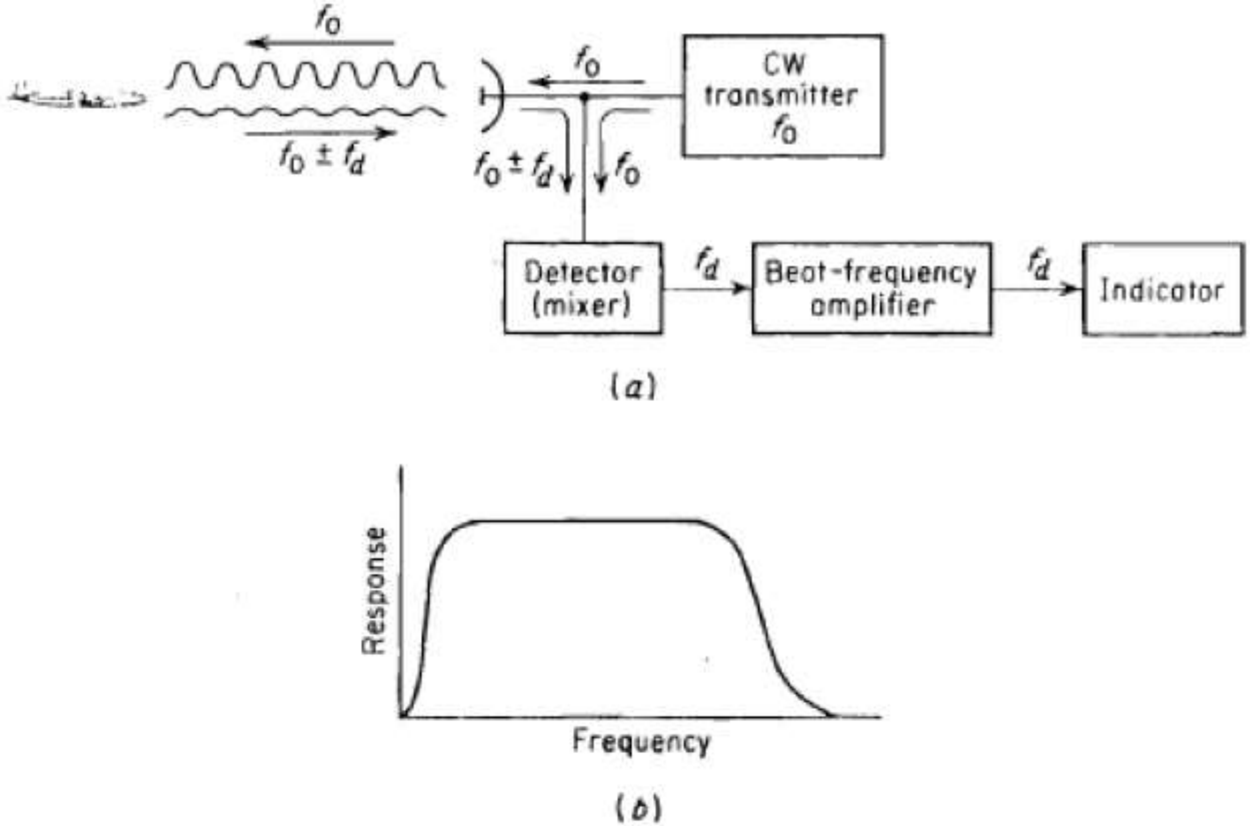


Figure2.1 (a) Simple CW radar block diagram; *(b)* response characteristic beat-frequency

The block diagram of CW Doppler Radar contains a set of blocks and the **function** of each block is mentioned below.

- **CW Transmitter:** It produces an analog signal having a frequency of f_o. The output of CW Transmitter is connected to both transmitting Antenna and Mixer-I.

- **Local Oscillator:** It produces a signal having a frequency of f_l. The output of Local Oscillator is connected to Mixer-I.

- **Mixer-I:** Mixer can produce both sum and difference of the frequencies that are applied to it. The signals having frequencies of f_o and f_l are applied to Mixer-I. So, the Mixer-I will produce the output having frequencies $f_o + f_l$ or $f_o - f_l$.

- **Side Band Filter:** As the name suggests, side band filter allows a particular side band frequencies — either upper side band frequencies or lower side band frequencies. The side band filter shown in the above figure produces only upper side band frequency, i.e., $f_o + f_l$.

- **IF Amplifier:** IF amplifier amplifies the Intermediate Frequency (IF) signal. The IF amplifier shown in the figure allows only the Intermediate Frequency, $f_l \pm f_d$ and amplifies it.
- **Detector:** It detects the signal, which is having Doppler frequency, f_d.
- **Doppler Amplifier:** As the name suggests, Doppler amplifier amplifies the signal, which is having Doppler frequency, f_d.
- **Indicator:** It indicates the information related relative velocity and whether the target is inbound or outbound.

CW Doppler Radars give accurate measurement of **relative velocities**. Hence, these are used mostly, where the information of velocity is more important than the actual range.

If CW Doppler Radar uses the Frequency Modulation, then that Radar is called FMCW **Doppler Radar** or simply, **FMCW Radar**. It is also called Continuous Wave Frequency Modulated Radar or CWFM Radar. It measures not only the speed of the target but also the distance of the target from the Radar.

ISOLATION BETWEEN TRANSMITTER AND RECEIVER

1. Isolation between the transmitted and the received signals is achieved via separation in frequency as a result of the doppler effect.
2. In practice, it is not possible to eliminate completely the transmitter leakage. However, transmitter leakage is not always undesirable.
3. 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.

4. 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.
5. 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.

- In CW Radars 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

- 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. Turnstile junctions achieveisolationsashighas40to60dB.
- The use of orthogonal polarizations for transmitting and receiving is limited to short range radars because of the relatively small amount of isolation that can be obtained.

- The largest isolations are obtained with two antennas: one for transmission, the other for reception-physically separated from one another. Isolations of the order of 80 dB or more are possible with high-gain antennas. The more directive the antenna beam and the greater the spacing between antennas, the greater will be the isolation. A common radome enclosing the two antennas should be avoided since it limits the amount of isolation that can be achieved.

NON ZERO IF RECEIVER

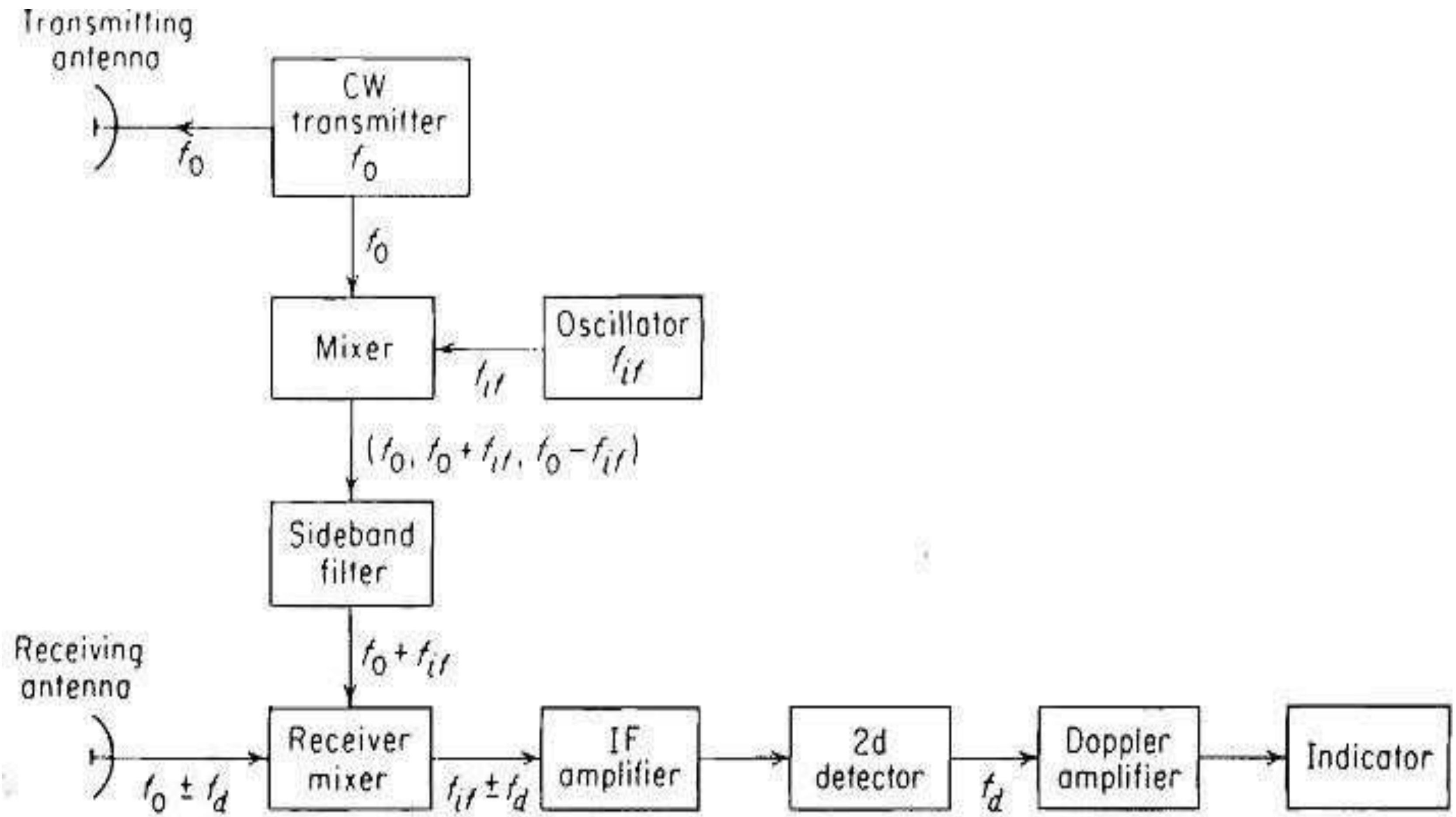
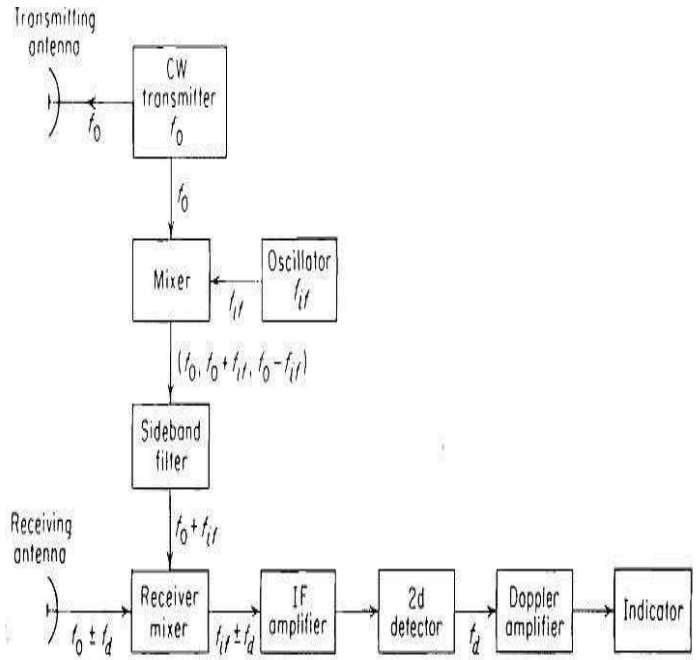
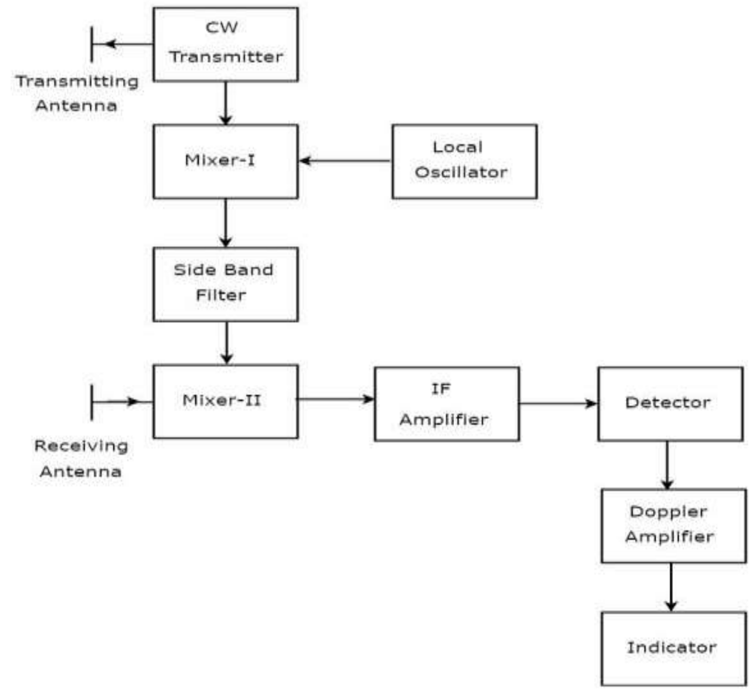


Fig 2.3 Block diagram of a CW Doppler radar with nonzero IF receiver, also called sideband super heterodyne Receiver



Block diagram of a CW Doppler radar with nonzero IF receiver, also called sideband super heterodyne Receiver



Block diagram of a CW Doppler radar with zero IF receiver

NON ZERO IF RECEIVER

1. 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.
2. The simpler receiver is not as sensitive because of increased noise at the lower intermediate frequencies caused by **flicker effect.**
3. Flicker-effect noise occurs in **semiconductor devices such as diode detectors and cathodes of vacuum tubes.**
4. 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.

NON ZERO IF RECEIVER

5. 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 Transmitter power, or increase antenna aperture.**

7. 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.
8. The improvement in receiver sensitivity with an intermediate-frequency super heterodyne might be as much as 30 dB over the simple receiver.

RECEIVER BANDWIDTH REQUIREMENT

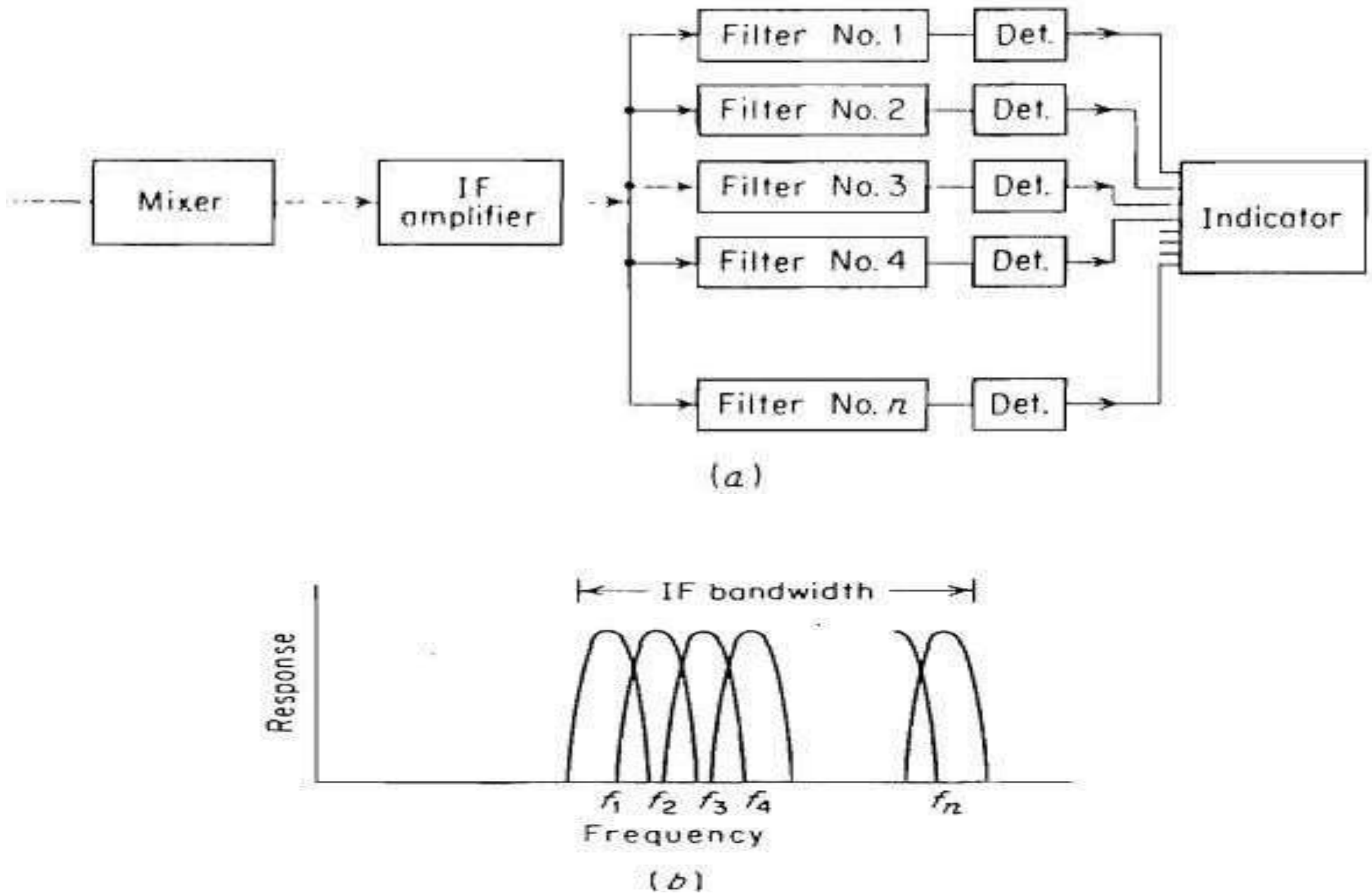


Fig 2 .4 (a)Block diagram of IF Doppler filter bank (b) frequency-response characteristic of Doppler filter bank

1. 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.**
2. 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.
3. 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.

4. 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.

Also matched filter could be specified as per requirement.

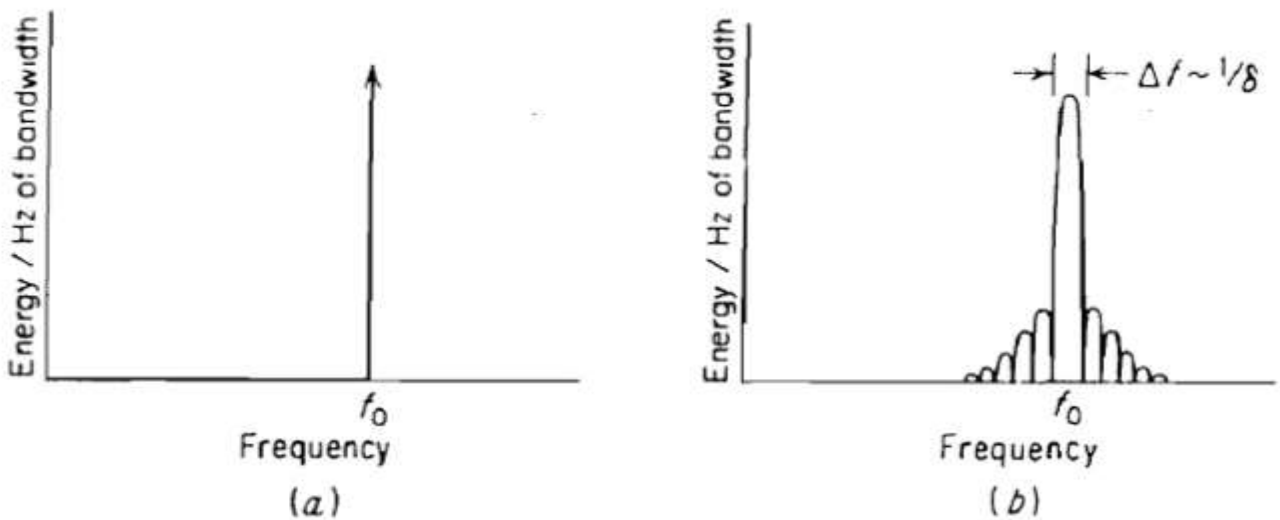


Fig. Frequency spectrum

5. If the received waveform were a sine wave of infinite duration, its frequency spectrum would be a delta function and the receiver bandwidth would be infinitesimal.
6. But a sine wave of infinite duration and an infinitesimal bandwidth cannot occur in nature.
7. The more normal situation is an echo signal which is a sine wave of finite rather than infinite duration.

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.

11. Assume a CW radar with an antenna beamwidth of Θ_B deg. scanning at the rate of Θ_s deg/s.
12. The time on target (duration of the received signal) is = Θ_B / Θ_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.
13. Although this is not an exact relation, it is a good enough approximation for purposes of the present discussion.
14. If the antenna beamwidth were 2o and if the scanning rate were 360/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.

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.

IDENTIFICATION OF DOPPLER DIRECTION IN CW RADAR

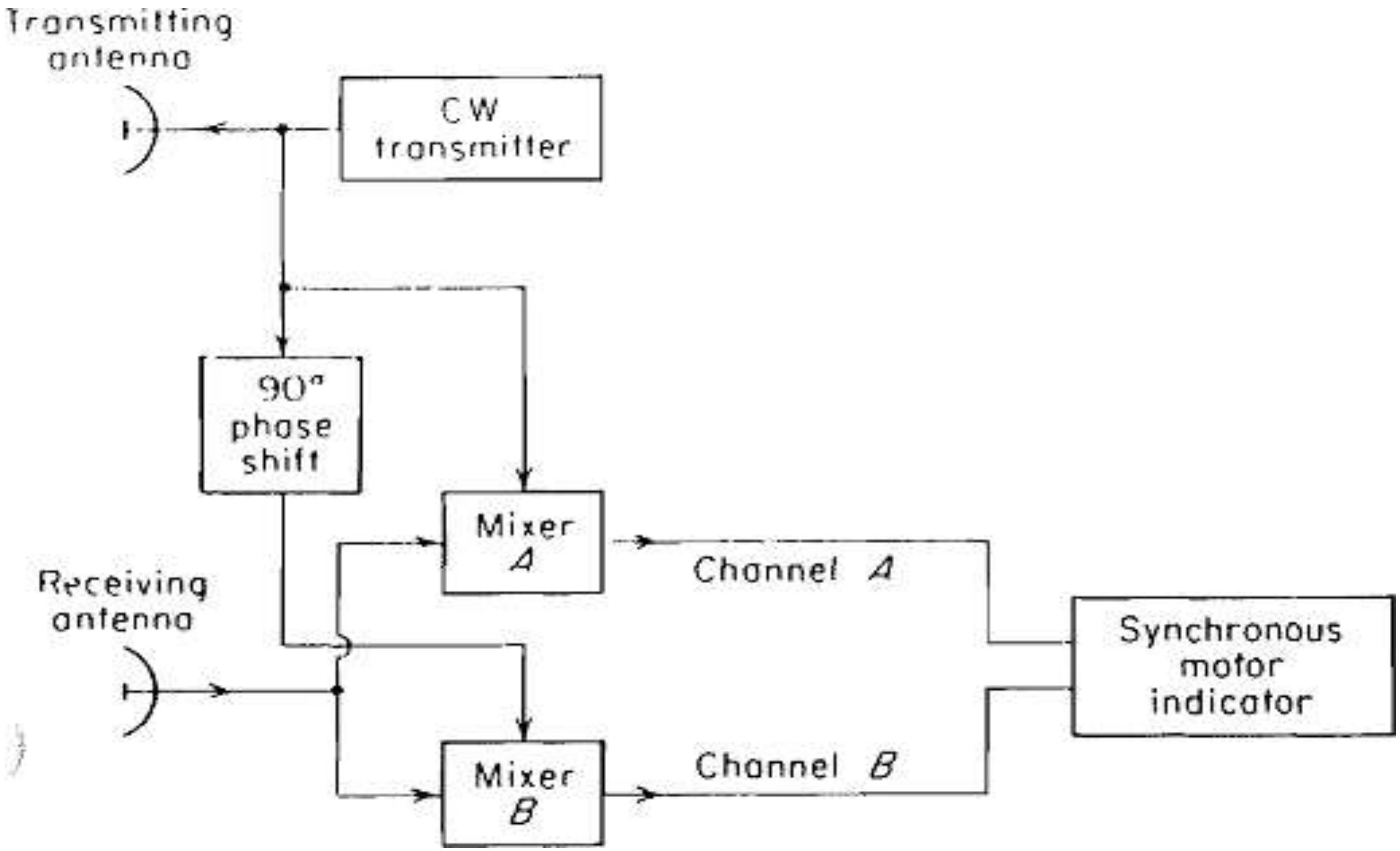


Fig 2.5 block diagram of Doppler direction in CW RADAR

IDENTIFICATION OF DOPPLER DIRECTION IN CW RADAR

$$E_t = E_0 \cos \omega_0 t \tag{3.4}$$

the echo signal from a moving target will be

$$E_r = k_1 E_0 \cos [(\omega_0 \pm \omega_d)t + \phi] \tag{3.5}$$

where E_0 = amplitude of transmitter signal
k_1 = a constant determined from the radar equation
ω_0 = 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 by splitting the received signal into two channels as shown in Fig. 3.8. 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

$$E_A = k_2 E_0 \cos (\pm \omega_d t + \phi) \tag{3.6}$$

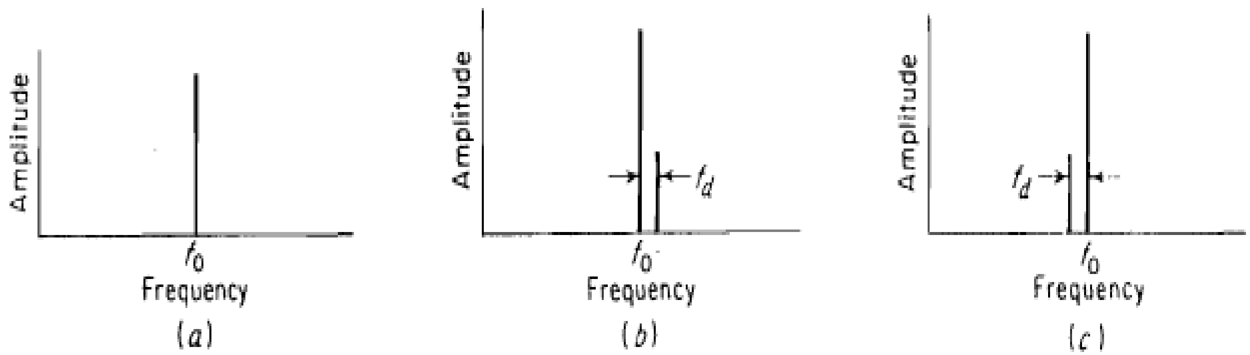


Figure 3.7 Spectra of received signals. (*a*) No doppler shift, no relative target motion; (*b*) approaching target; (*c*) receding target.

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

$$E_B = k_2 E_0 \cos\left(\pm\omega_d t + \phi + \frac{\pi}{2}\right) \tag{3.7}$$

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

$$E_A(+) = k_2 E_0 \cos(\omega_d t + \phi) \qquad E_B(+) = k_2 E_0 \cos\left(\omega_d t + \phi + \frac{\pi}{2}\right) \tag{3.8a}$$

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

$$E_A(-) = k_2 E_0 \cos(\omega_d t - \phi) \qquad E_B(-) = k_2 E_0 \cos\left(\omega_d t - \phi - \frac{\pi}{2}\right) \tag{3.8b}$$

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.[18] The direction of motor rotation is an indication of the direction of the target motion.

Advantages and disadvantages of CW Radars:

- The principal advantage of CW Doppler radar over the other (non radar) methods of measuring speed is that there need not be any physical contact with the object whose speed is being measured. In industry this is used to measure turbine-blade vibration, the peripheral speed of grinding wheels, and the monitoring of vibrations in the cables of suspension bridges.

- Most of the above applications can be satisfied with a simple, solid-state CW source with powers in tens of milliwatts

- 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. (Shown below)

- The difficulty of eliminating the leakage of the transmitter signals into the receiver has limited the utility of unmodulated CW radar for many long-range applications.

- The CW radar, when used for short or moderate ranges, is characterized by simpler equipment than a pulse radar. The amount of power that .can be used with a CW radar is dependent on the isolation that can be achieved between the transmitter and receiver since the transmitter noise that finds its way into the receiver limits the receiver sensitivity. (The pulse radar has no similar limitation to its maximum range because the transmitter is not operative when the receiver is turned on.)

- Major disadvantage 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.

FREQUENCY MODULATED CW RADAR

- The inability of the simple CW radar to measure range is related to the relatively narrow spectrum (bandwidth) of its transmitted waveform. Some sort of timing mark must be applied to a CW carrier if range is to be measured

- .The timing mark permits the time of transmission and the time of return to be recognized.

- A widely used technique to broaden the spectrum of CW radar is to frequency-modulate the carrier. The timing mark is the changing frequency.

RANGE AND DOPPLER MEASUREMENT

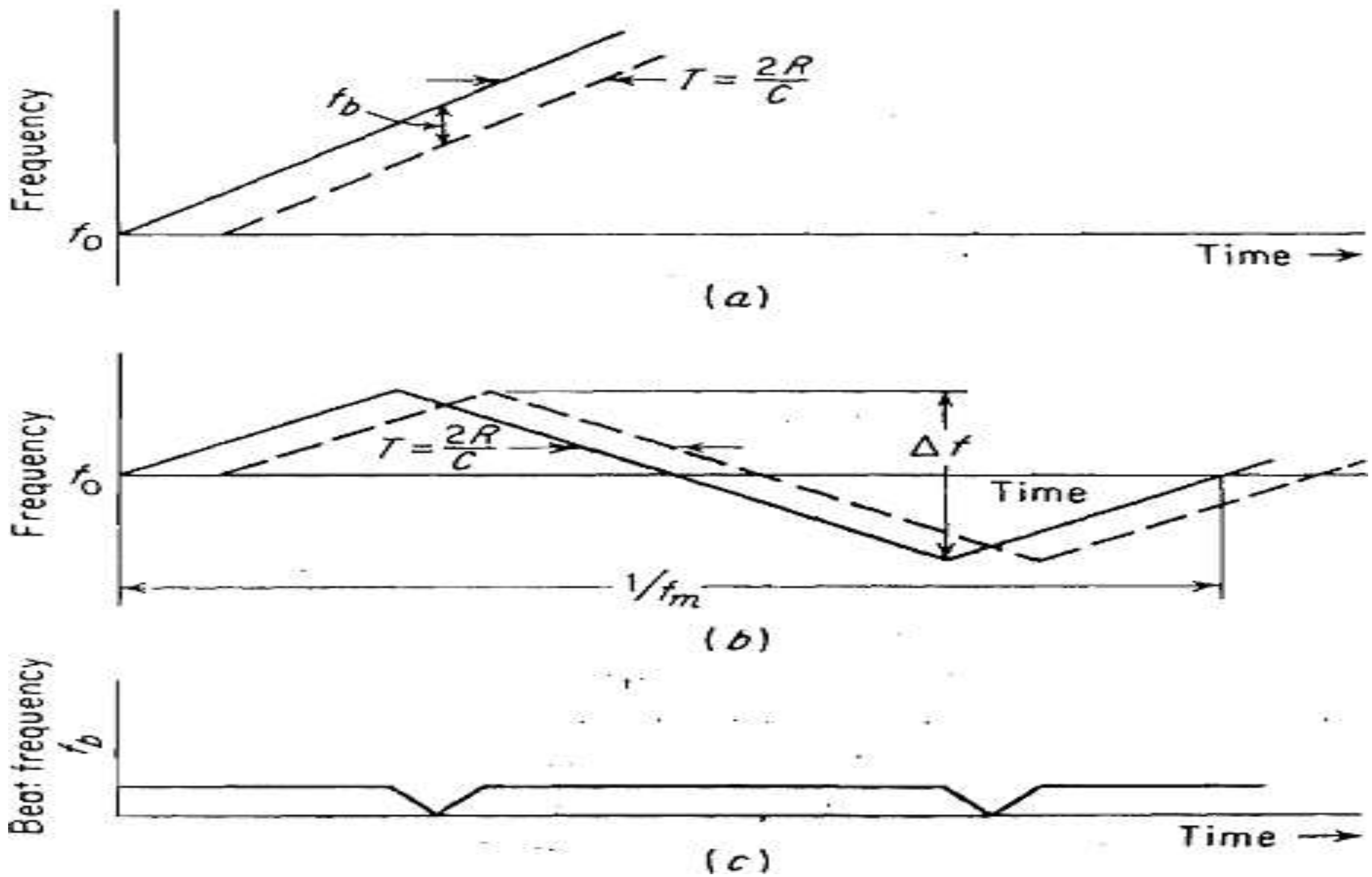


Fig 2.7

(a) Linear frequency modulation (b) triangular frequency modulation; (c) beat note of (b).

Range and doppler measurement

In the frequency-modulated CW radar (abbreviated 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.

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 ***fb will be produced.***

If there is no Doppler frequency shift, the beat note (difference frequency) is a measure of the target's range and ***fb = fr where fr is the beat frequency due only to the target's range.***

If the rate of change of the carrier frequency is *f0 , the beat frequency is*

$$f_r = \dot{f}_0 T = \frac{2R}{c}\dot{f}_0$$

If the frequency is modulated at a rate fm over a range **Δf the beat frequency is**

$$f_r = \frac{2R}{C}.2\,f_m.\Delta f = \frac{4Rf_m.\Delta f}{C}$$

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

$$R = \frac{C.f_r}{4\,f_m.\Delta f}$$

FM-CW RADAR

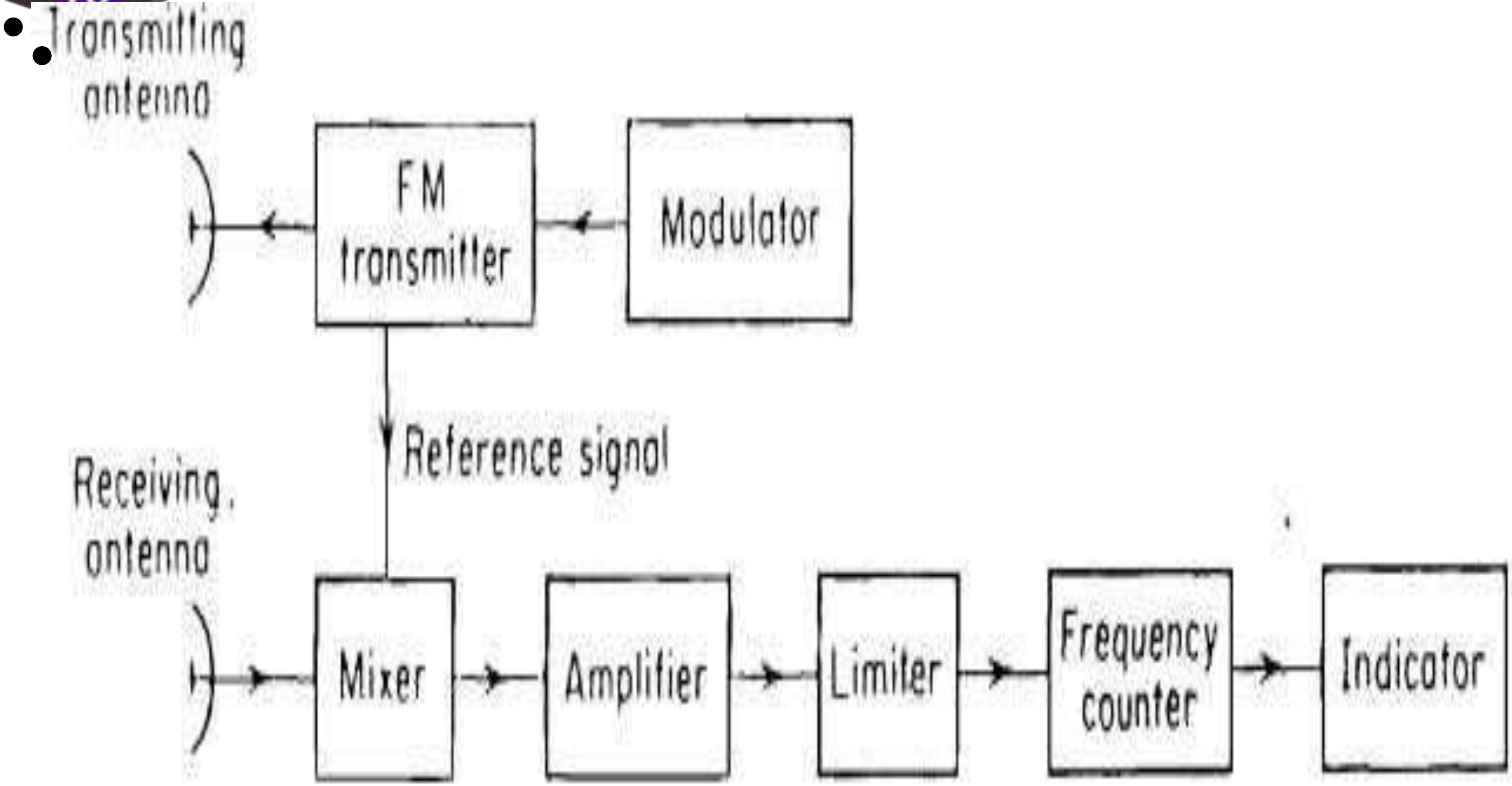
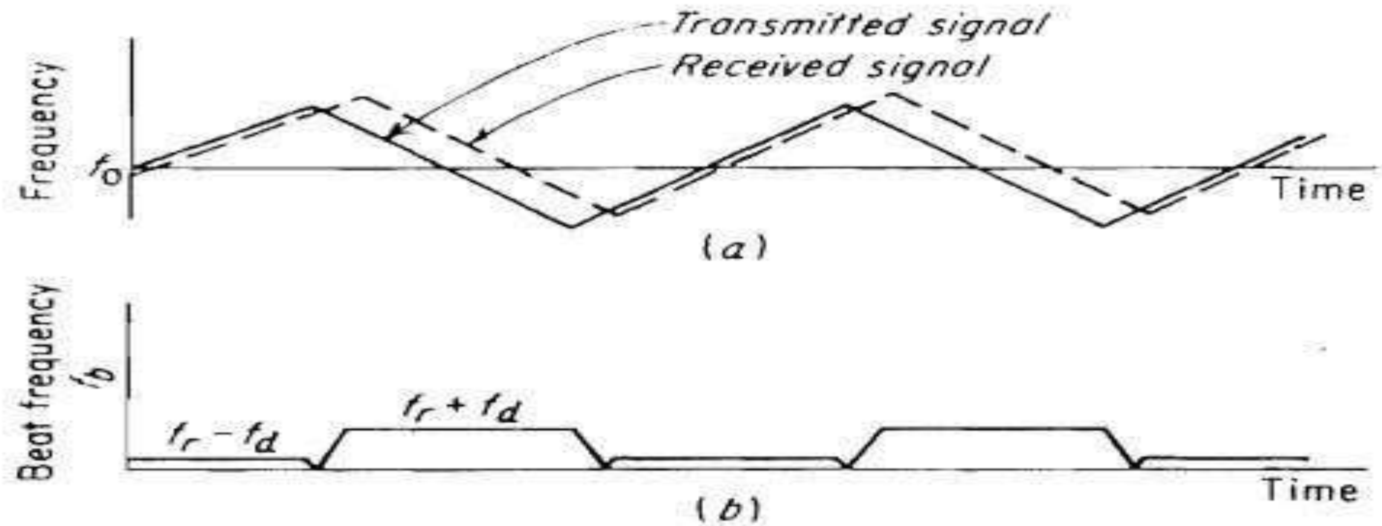


Fig 2.6 Block diagram of FM-CW RADAR

The FMCW-Radar [ART Midrange]() uses separate [offset antennas]() for transmitting and receiving

RANGE AND DOPPLER MEASUREMENT



(a)Transmitted (solid curve) and echo (dashed curve)

(b)beat frequency

APPROACHING AND RECEDING TARGET

- FM cycle will be the difference between the beat frequency due to the range fr, and the doppler frequency shift fd

- $$fb(up) = fr - fd$$
- $$fb(down) = fr + fd$$

- The range frequency fr, may be extracted by measuring the average beat frequency that is

- fr = 1/2[fb(up) + fb(down)]
- fd = 1/2[fb(down)-fb(up)]
- fr > fd Target Approaching
- fr < fd Target Receding

Example1: Determine the Range and Doppler velocity of an approaching target using a triangular modulation FMCW Radar. Given : Beat frequency $f_b(up)$ = 15KHz and $f_b(down)$ = 25KHz , modulating frequency : 1MHz, Δf : 1KHz and Operating frequency : 3Ghz

Solution:

We know $f_r = ½[f_b(up) + f_b(down)] = ½(15+25) = 20$ Khz

$f_d = ½[f_b(down) - f_b(up)] = ½(25-15) = 5$ Khz

The Range **R** in terms of f_r, f_m and Δf is given by : **R** = $c f_r / 4 f_m . \Delta f$

$= (3\times10^8) 20\times10^3 / 4(1\times10^6 \times 1\times10^3)$ mtrs = 1500 mtrs = 1.5 Kms

FM-CW ALTIMETER

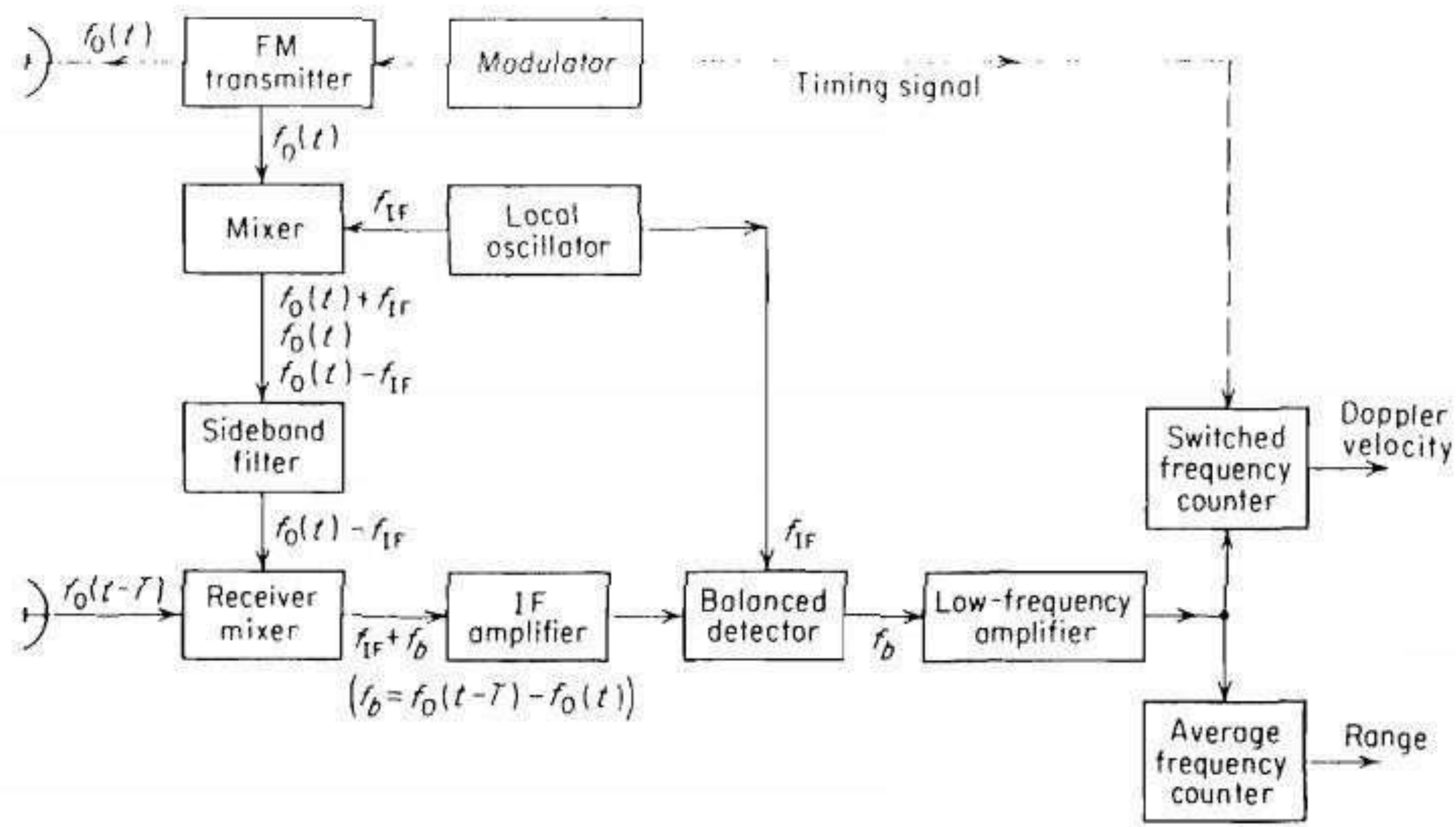


Fig 2.9 Block diagram of FM-CW Altimeter

The FM-CW radar principle is used in the aircraft radio altimeter to measure height above the surface of the earth.

Since the relative motion between the aircraft and ground is small, the effect of the doppler frequency shift may usually be neglected.

The band from 4.2 to 4.4 **GHz is reserved for radio altimeters, although they have in the past operated at UHF**

The transmitter power is relatively low and can be obtained from a CW magnetron, a backward-wave oscillator, or a reflex klystron, but these have been replaced by the solid state transmitter.

FM Modulator − It produces a Frequency Modulated (FM) signal having variable frequency, fo(t) and it is applied to the FM transmitter.

FM Transmitter − It transmits the FM signal with the help of transmitting Antenna. The output of FM Transmitter is also connected to Mixer.

Local Oscillator − In general, Local Oscillator is used to produce an RF signal. But, here it is used to produce a signal having an Intermediate Frequency, f_{IF} . The output of Local Oscillator is connected to both Mixer and Balanced Detector.

Mixer − Mixer can produce both sum and difference of the frequencies that are applied to it. The signals having frequencies of $f_0(t)$ and f_{IF} are applied to Mixer. So, the Mixer will produce the output having frequencies

$$f_0(t),\ f_0(t) + f_{IF},\ f_0(t) - f_{IF}$$

Side Band Filter − It allows only one side band frequencies, i.e., either upper side band frequencies or lower side band frequencies. The side band filter shown in the figure produces only lower side band frequencies

$$f_0(t) - f_{IF}$$

Receiver Mixer − Mixer can produce both sum and difference of the frequencies that are applied to it. The signals having frequencies of $f_0(t) - f_{IF}$ and $f_0(t-T)$ are applied to Receiver Mixer. So, the Receiver Mixer will produce the output having frequency either fo(t−T)+fo(t)−fIF or fo(t−T)−fo(t)+fIF. But its allow only

$$f_0(t-T) + f_0(t) - f_{IF}, \; f_0(t-T) - f_0(t) + f_{IF}$$

$$f_b = f_0(t-T) - f_0(t)$$

$$f_b + f_{IF}$$

Balanced Detector − It is used to produce the output signal having frequency of fb, The output of Balanced detector is applied as an input to Low Frequency Amplifier.

Low Frequency Amplifier − It amplifies the output of Balanced detector to the required level. The output of Low Frequency Amplifier is applied to both switched frequency counter and average frequency counter.

Switched Frequency Counter − It is useful for getting the value of Doppler velocity.

Average Frequency Counter − It is useful for getting the value of Range.

MEASUREMENT OF ERRORS

The absolute accuracy of radar altimeters is usually of more importance at low altitudes than at high altitudes. Errors of a few meters might not be of significance when cruising at altitudes of 10 km, but are important if the altimeter is part of a blind landing

error are caused by the circuits and transmission lines,
errors caused by multiple reflections and transmitter leakage, and the frequency error due to the turn-around of the frequency modulation

The discreteness of the frequency measurement gives rise to an error called the fixed error, or step error. It has also been called the **quantization error,**

MEASUREMENT OF ERRORS

- The average number of cycles N of the beat frequency fb in one period of the modulation cycle fm is $\frac{\overline{f_b}}{f_m}$, where the bar over , denotes time average.

$$R = c\,N / 4\,\Delta f$$

$$R = \frac{C.\,f_r}{4\,f_m.\Delta f}$$

Where, R = range (altitude). m

c = velocity of propagation. m/s

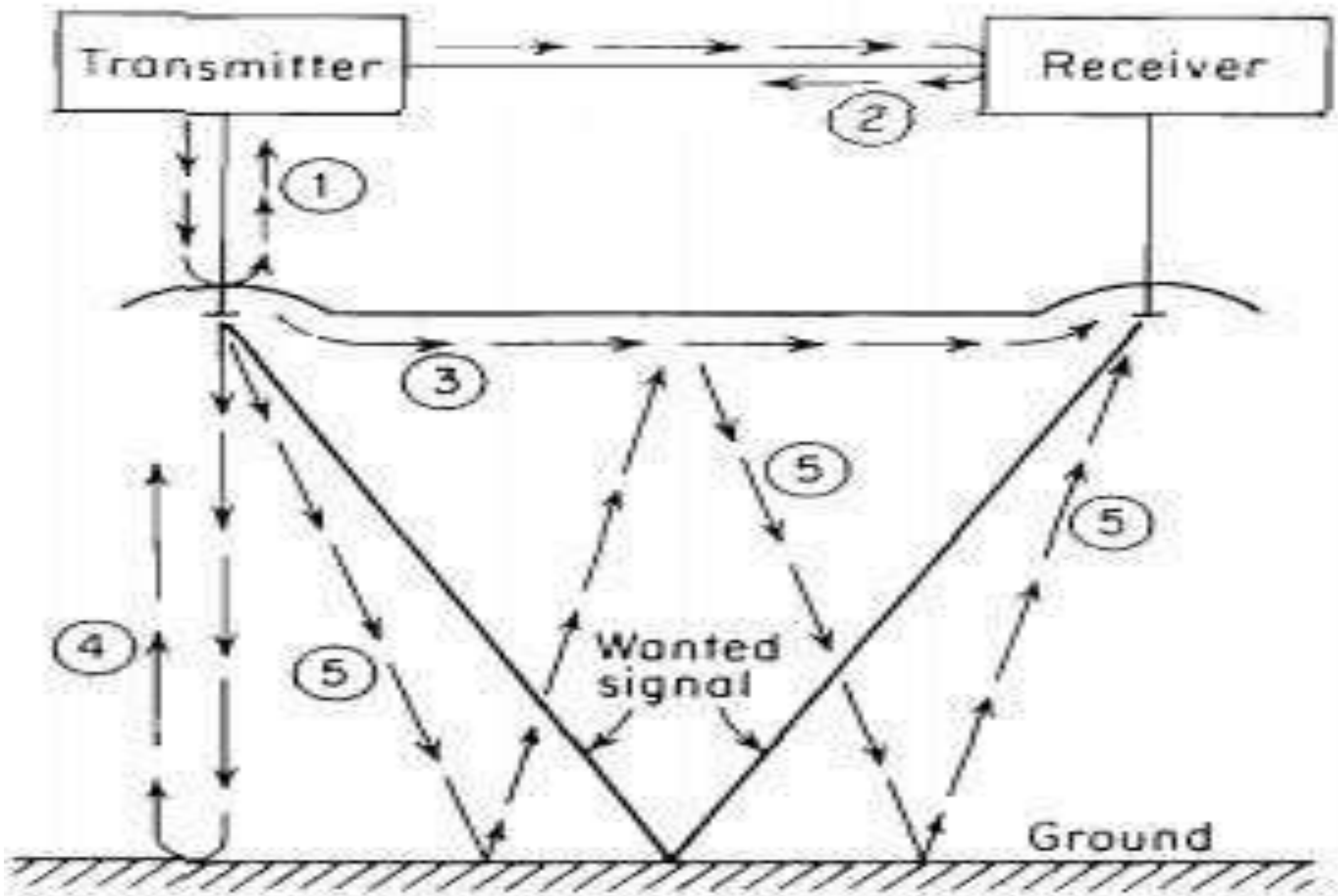
Δf = frequency excursion. Hz

- Since the output of the frequency counter N isan integer, the range will be an integral multiple of c / 4 Δ f and will give rise to a quantization error equal to

$$\delta R = c / 4\,\Delta f$$

$$\delta R\,(m) = 75 / \Delta f\,(MHz)$$

Mention the unwanted signals in FM altimeter.



UNWANTED SIGNAL

1. The reflection of the transmitted signals at the antenna caused by impedance mismatch.
2. The standing-wave pattern on the cable feeding the reference signal to the receiver, due to poor mixer match.
3. The leakage signal entering the receiver via coupling between transmitter and receiver antennas. This can limit the ultimate receiver sensitivity, especially at high altitudes.
4. The interference due to power being reflected back to the transmitter, causing a change in the impedance seen by the transmitter. This is usually important only at low altitudes. It can be reduced by an attenuator introduced in the transmission line at low altitude or by a directional coupler or an isolator.
5. The double-bounce signal.

MULTIPLE FREQUENCY CW RADAR

Derive an expression for unambiguous range of a two frequency CW radar.

Although it was indicated earlier that CW radar can 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

Consider a CW radar radiating a single-frequency sine wave of the form $\sin 2\pi f_o t$ the signal travels to the target at a range R and returns to the radar after a time T = 2R/c where c is the velocity of propagation

The echo signal received at the radar is $\sin[2\pi f_o(t - T)]$. *If* the transmitted and received signals are compared in a phase detector, the output is proportional to the phase difference between the two and is given by : $\Delta\phi = 2\pi f_0 T = 4\pi f_0 R/c$.
The phase difference may therefore be used as a measure of the range, or

$$R = \frac{c\,\Delta\phi}{4\pi f_0} = \frac{\lambda}{4\pi}\Delta\phi$$

MULTIPLE FREQUENCY CW RADAR

The voltage waveforms of the two components of the transmitted signal ***v1T and v2T may be written as***

$$v_{1T} = \sin\,(2\pi f_1 t + \phi_1)$$

$$v_{2T} = \sin\,(2\pi f_2 t + \phi_2)$$

where ϕ1 and ϕ2 are arbitrary (constant) phase angles.

The echo signal is shifted in frequency by the Doppler
Effect. The form of the Doppler shifted is at each of the two frequencies f1 and f2 be written as

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

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

MULTIPLE FREQUENCY CW RADAR

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

- Since the two RF frequencies f1 and f2 are approximately the same the Doppler frequency shifts fd1 and fd2 are approximately equal to one another. Therefore

fd1 = fd2 = fd

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

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

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

MULTIPLE FREQUENCY CW RADAR

- The phase difference between these two components is

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

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

- There is a limit to the value of Δf, since Δϕ cannot be greater than 2π radians if the range is to remain unambiguous

  Runamb = c / 2Δf

  Δf must be less than c/2 Runamb

- When Δf is replaced with Pulse Repetition Rate gives Maximum Unambiguous Range of a Pulse Radar.

Benefits or Advantages of FMCW Radar

Following are the benefits or **advantages of FMCW Radar**:

➡FMCW radar is called altimeter. It is used in aircraft to measure height above the earth.

➡It uses low power for transmission. This can be supplied by many solid state devices such as magnetron, BWO, reflex klystron etc.

➡The super-heterodyne based architecture delivers good sensitivity and stability.

➡It offers higher bandwidth compare to CW radar.

Drawbacks or disadvantages of FMCW Radar

Following are the **disadvantages of FMCW Radar**:

➡They are used for targets at very short ranges. This is due to use of lower peak output power.

➡Due to use of lower transmit power, the signal gets attenuated and affected due to atmosphere and channel before it is received by the receiver.

➡It is more expensive compare to pulsed radar.

➡The transmissions from FMCW radar is interfered from other nearby radio systems due to use of large range of frequencies and low peak power for transmitter part.

With a transmit (CW) frequency of 5GHz, calculate the Doppler frequency seen by a Stationary Radar when the target radial velocity is 100 km/h (62.5 mph)?

Compute the velocity of the target if it produces a Doppler shift of 1 KHz and operating wavelength is 3 cm. Derive the relationship used

DIGITAL RESOURCES

- Lecture Notes –RADAR SYSTEMS-UNIT 2 LECTURE NOTES.pdf
- Video Lectures - https://youtu.be/LomqBVYbMUQ
- E-Book - radar-systems-skolnik.pdf
- Model Papers - 15A04705_Radar Systems.pdf